To the Graduate Council:

I am submitting herewith a thesis written by Sami S. Ghezawi entitled "An Evaluation of a Traffic Signal with White Bar Strobe Light." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

J. B. Humphreys,
Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Provost and Dean of
The Graduate School

AN EVALUATION OF A TRAFFIC SIGNAL WITH WHITE BAR STROBE LIGHT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Sami S. Ghezawi

June 1988

DEDICATION

This thesis is dedicated to my father, Sa'id M. Ghezawi, who supported me financially and morally throughout this endeavor. His love and encouragement made this dream come true.

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ABSTRACT

The best drivers occasionally overlook cues and make errors which sometimes result in traffic accidents. Therefore, the need to draw drivers attention to unexpected and/or difficult to perceive traffic signals is a concern to traffic engineers. The objective of this research was to study a traffic signal with a strobe light, and to determine the influence of the strobe, if any, on drawing drivers attention to a red signal indication. The measures of effectiveness selected for this study were vehicle deceleration rates, speed profiles, perception - reaction times, and violations of the red of the red indication.

Two data collection techniques were selected for this study. First, a 20-pen graphic recorder was used for data collection to allow the determination of deceleration rates, speed profiles, and violations. Secondly, a stop-watch was used to measure drivers perception -reaction times. A before-and-after study was used to evaluate driver performance at a single signalized intersection approach. This study design negated the effects of site differences, and allowed a direct comparison of driver performance at the traffic signal with and without a strobe light. Statistical analyses were used to determine if differences determined between the before-and-after study were statistically significant.

This study concluded that the use of a strobe light at a difficult to discern traffic signal had an effect on driver's performance measures. The results show that driver perception- reaction time were lower. Indications are that drivers did apply their brakes earlier and made a safer and more gradual approach to the traffic signal. Furthermore, the maximum deceleration rate was reduced from an "undesirable level" to a "practical level" as defined by The Traffic Engineering Handbook. The point at which this decrease in deceleration rate occurred was located 100 feet upstream from the traffic light.

As a result of the limited sample size and the single location and approach, the results showed that future studies are warranted on the subject of strobes and their effect on driver's performance.

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CHAPTER I

INTRODUCTION

Background

The Manual on Uniform Traffic Control Devices (MUTCD) does not mention highway traffic signals with white bar strobes. The use of the strobe as a traffic control device has not been officially approved. However, several cities across the United States have received permission to experiment with highway traffic signals with strobes from the National Committee on Uniform Traffic Control Devices (NCUTCD) and/or the Federal Highway Administration (FHWA). "Among the jurisdictions receiving such permission are the District of Columbia; Montgomery County, Maryland; City of Portland, Oregon; City of Charleston, South Carolina; State of Kansas; and the State of Indiana."[1] Highway traffic signals with white strobes have been used to draw the driver's attention to a red signal indication, which could result in fewer collisions at signalized intersections. Although there are published studies dealing with the latter subject, only limited research, most of which is unpublished, addresses the issue of strobes as a device to draw the driver's attention to a red signal indication.

Objective

The objective of this research was to study a highway traffic signal with a horizontal white bar strobe positioned in front of a normal 12" red traffic signal lens, and to determine the influence of strobes, if any, on drawing the driver's attention to an already red signal indication.

In order to evaluate the effect of a strobe light on driver performance at a signalized intersection, vehicle speed profiles, deceleration rates, and driver perception-reaction times were determined and subsequently analyzed for both the existing traffic signal and the traffic signal with the white bar strobe.

Limitations

The results and conclusion presented in this study are limited, and should not be generalized due to the following reasons:

1 - This study was limited to only one signalized intersection.

2 - The sample size was small due to the limited resources.

Even though this study had some limitations, it provides some insight to an otherwise unexplored area of traffic engineering.

CHAPTER II

LITERATURE REVIEW

Introduction

An intersection is defined as that area where two or more roads meet. Most intersections in the highway system today are at-grade intersections as opposed to grade-separated intersections or interchanges. Various methods can be used to control conflicting traffic movements at intersections, including the following:

1. Basic Right-of-way Rule
2. Yield sign
3. Stop sign
4. Multi-way stop
5. Traffic signals

These methods of control are presented in an ascending degree of control and restrictions.[2] The Manual of Uniform Traffic Control Devices (MUTCD) spells out in some detail different warrants concerning the installation of the above traffic control devices. Nevertheless, these warrants must be used in conjunction with professional judgement based on experience and consideration of all related factors.

At a high speed signalized intersection, traffic signals are designed and placed based upon engineering principles and guidelines established in the MUTCD. The

ability of drivers to anticipate or discern a traffic signal downstream would enable them to make simple decisions about whether or not to prepare to stop. If their information needs are met, drivers should perform in an acceptable and safe manner.

When approaching a signalized intersection, drivers need to be aware of the presence of the traffic signal. This can be done by placing signal ahead signs (Fig. 2.1). As a practical matter these warning devices are usually installed only where horizontal or vertical curves or other sight distance restrictions precede the traffic signal and/or at the installation of a new signal. In addition, they have been used at high accident locations (HAL's). The MUTCD states "A Signal Ahead sign is intended for use in advance of any signalized location where physical conditions prevent drivers from having a continuous view of at least two signal indications"[3] for distances as shown on the next page (Table 2.1).

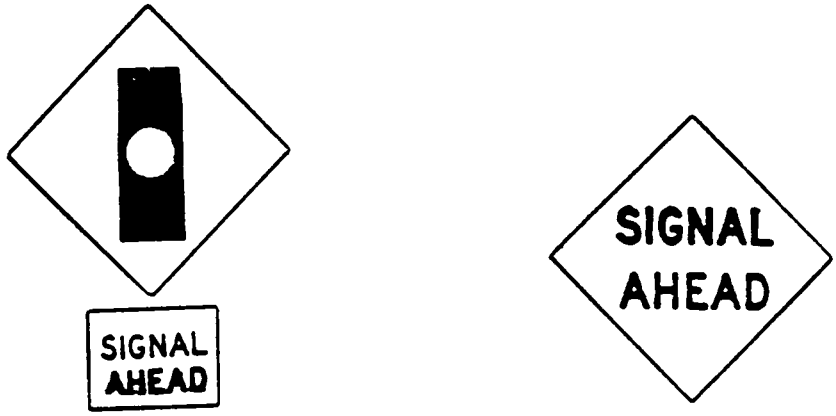


FIGURE 2.1. Signal Ahead Sign.

Table 2.1. Minimum Visibility Distance for a Given Speed.

85 Percentile Speed (mph)	Minimum Visibility Distance (Ft.)
20	100
25	175
30	250
35	325
40	400
45	475
50	550
55	625
60	700

Previous Studies

Most drivers encounter traffic signals on a daily basis and expect a signal interval to change frequently. However, traffic conflicts at signalized intersections occur regularly due to a delayed reaction of drivers approaching a red signal. A good driver is one who constantly scans the road ahead and acts accordingly in a safe manner, but even the best drivers occasionally overlook cues and make errors which sometimes result in traffic accidents. Therefore, the need to improve driver awareness of unexpected or difficult to discern traffic signals is a concern to the traffic engineer.

A communication system developed by The University of New Mexico dealt with whether an in-vehicle colored-band display could assist drivers in making a smoother and safer

approach to a traffic signal. The light display "illuminated 1 of 3 colored lights on the display panel - red, yellow, or green"[4] to alert a driver in "advance that he was approaching a traffic light and exactly what the signal indication would be on his arrival at the signal if he continued at his present speed."[4] Their research showed that such a display did enable many drivers to make a safer and gradual approach to a traffic signal.

A dissertation presented to the University of Tennessee has addressed the issue of the driver's performance measures at highway-railway grade crossings. Highway traffic signals with white bar strobes in front of all red lenses were compared with other highway-grade crossing warning devices. Research indicated that the installation of strobes was effective in improving driver behavior when addressing warning and clearance times at the crossings, but no significant difference in speed profile and/or brake reaction times was detected.[5]

As mentioned earlier, highway traffic signals with strobes have been used in other jurisdictions to draw driver's attention to a red signal indication which could result in fewer collisions at signalized intersections. Previous studies[1] have looked at "number of accidents" and "accident rates"[1] and found that they have decreased,

however the decreases were not large enough to be statistically significant due to the limited amount of data available.

One leading manufacturer of a signal strobe light is Eliate Equipment. According to the 1984 price list, the Barlow Light, which is a strobe light mounted in the red signal section lens, costs approximately 210 dollars. Today, the manufacturers have changed its name to Safety Beams and they cost approximately 575 dollars.[6]

In summary, highway traffic signals with strobes have been used for a number of years in different cities, but have not yet been adopted in the MUTCD or other national standards as an official traffic control device. There are some published reports concerning safety and accident rates at signalized intersections with strobes. However, it is somewhat surprising there aren't any published reports which attempt to address and quantify the driver's behavior at signalized intersection with strobes. The driver's performance measures reported in this study include speed profiles, speed changes, deceleration levels, perception - reaction time, and violations.

In order to fully understand the concept of driver performance measures, the following has been presented.

Driver Performance at Signalized Intersection

Speed Profile. The speed profile of traffic approaching a traffic signal is a good and simple measure of driver performance. Speed profiles of vehicles vary under different signal displays, and along various sections of the road in advance of a traffic signal. When evaluating approach speed profiles in response to a particular signal display (i.e., a red signal indication), it should be recognized that the presence of another vehicle in front of the vehicle being observed will have an effect on the latter's approach speed.

Research in the past has shown that speed profiles varied from one signal display to another at different locations along the roadway. Figure 2.2 shows speed profiles for different signal displays with speed traps spaced 150 feet apart.[7]

Deceleration rate. Deceleration of vehicles occurs in two phases. First, when the foot is moved from the accelerator pedal, deceleration occurs due to resistance to motion and the braking effect of the engine. Secondly, when the foot is applied to the brake pedal, deceleration occurs due to the braking force on the wheels, restraining vehicle motion. Deceleration rates are useful for traffic engineers in estimating minimum stopping distances and in calculating traffic signal change intervals. The 1982

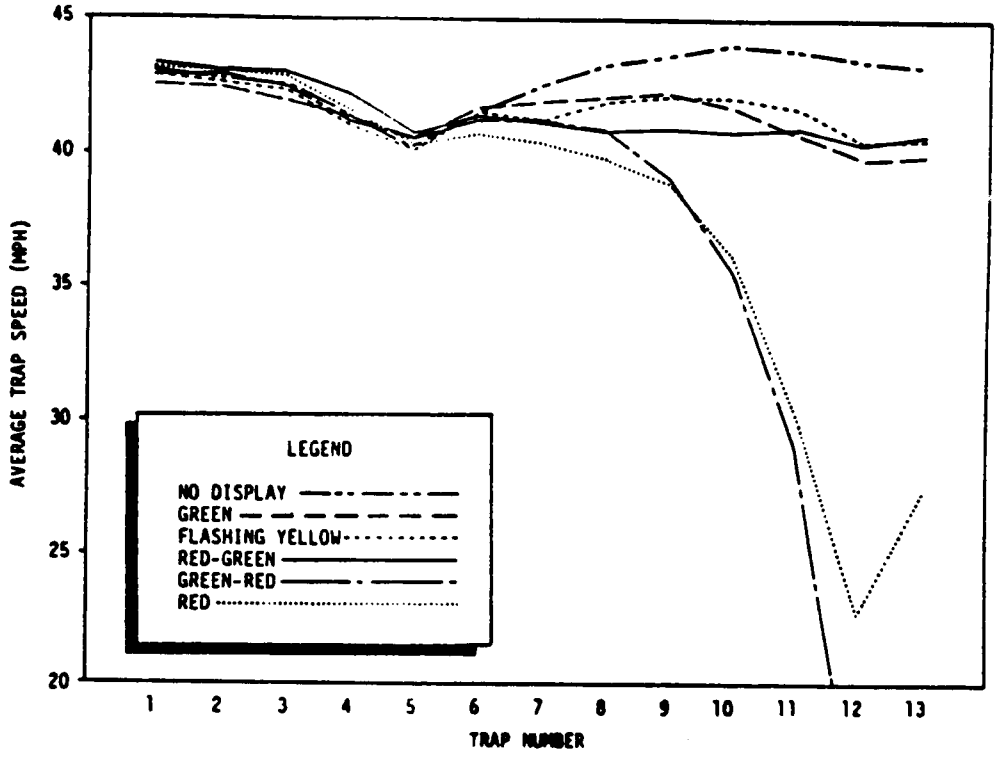


FIGURE 2.2. Average Speed Profiles of Traffic Having Initial Speeds Between 40 and 45 mph.

Transportation and Traffic Engineering Handbook recommends a deceleration of 10 feet per second per second (10 fps^2) to be used in calculating the length of a traffic signal change interval.[8]

Deceleration levels are thought to be good indicators of drivers performance at signalized intersections. In an ideal condition drivers anticipating a stop should do so in a smooth and gradual manner. However, if a driver is not anticipating a stop, maximum braking occurs, resulting in uncomfortable or emergency deceleration.

The Traffic Engineering Handbook[9] defines several levels of deceleration as follows:

1. Emergency - greater than 20 fps^2
2. Very uncomfortable - 14 to 20 fps^2
3. Uncomfortable - 11 to 14 fps^2
4. Undesirable - 8 to 11 fps^2
5. Practical - Less than 8 fps^2

Deceleration rate is calculated from the basic laws of motion. It is affected by speed, distance, and time, as shown in the following equations:

$$d = (V - Vo)/t$$

where: d = deceleration, fps^2
V = initial velocity, fps
Vo = Final velocity, fps
t = time over which change in velocity occurs, sec.

Normal deceleration levels observed for passenger cars on dry pavement are shown in Table 2.2, for stops from running speed of 15 and 30 mph, and for 10 mph slow downs from various running speeds. Deceleration rates up to 5.5 mphps ($8 fps^2$) are reasonably comfortable for car occupants.[8]

Deceleration values presented assume a level road. Supposedly, drivers will accept higher than normal deceleration levels on an upgrade and lower than normal on a downgrade.[5]

Perception - Reaction Time. Perception - Reaction time, often referred to as the PIEV time, is the total time required to perceive and react to a stimulus. At a signalized intersection, PIEV time is broken into several events which are:

1. Perception: The time it takes drivers to actually see the traffic signal.
2. Intellection/Emotion: The identification of the traffic signal and the decision making process.
3. Reaction/Volition: The actual execution of the decision.

These intervals of time cannot be separated during actual field measurements as it is impossible for an observer to differentiate when each of the above events started and/or ended. Therefore, the total time is generally reported.

Table 2.2. Normal Deceleration Rate.

Speed Change		Accelerations		Decelerations	
mph	kph	mphps	kphps	mphps	kphps
0–15	0–24	3.3	5.3	5.3	8.5
0–30	0–48	3.3	5.3	4.6	7.3
30–40	48–64	3.3	5.3	3.3	5.3
40–50	64–80	2.6	4.2	3.3	5.3
50–60	80–97	2.0	3.2	3.3	5.3
60–70	97–113	1.3	2.1	3.3	5.3

Several studies have measured perception-reaction time for a given driving task. In a study in the 1940's, over 1000 persons were tested in order to measure the time taken to apply the brakes after the driver sees a hazard. That research indicated that the average reaction time for men drivers was 0.57 sec. and for women drivers, 0.62 sec.[10] However, these times are faster than normal because drivers were anticipating some kind of a stimulus. Under actual conditions total PIEV time ranges from about 0.5 seconds to 4.0 seconds, depending on the complexity of the situation.[2] The extent of variation in PIEV time depends on the particular environmental condition, age, driver's sex, along with other factors.

CHAPTER III

FIELD DATA COLLECTION PROCEDURES

Introduction

Two independent data collection techniques were selected for this study of driver's performance measures at a signalized intersection. The techniques considered are the 20-pen graphic recorder and the stop-watch method, as discussed in the following pages. A before-and-after study approach was used to evaluate driver's performance at a signalized intersection. That is, data were collected at an existing intersection with a standard traffic signal installation, and then again at the same intersection with a horizontal white bar strobe positioned in front of the 12" red lens. This approach negated the effects of site differences, and allowed a direct comparison between the traffic signal with and without strobe. The installation of the white bar strobe in one of the traffic signal heads was performed by the Department of Traffic Engineering in Knoxville, Tennessee.

The measures of effectiveness selected for the evaluation of driver performance were as follows:

1 - Speed profiles;

2 - Deceleration rates;

3 - Perception - Reaction times; and

4 - Violations.

The general hypotheses tested was that the highway traffic signal with strobes would result in (a) lower peak deceleration rates, (b) shorter perception - reaction times, and (c) fewer violations. Thus, the overall null hypotheses were that there was no differences in driver performance measures when comparing response to the before and after condition. The hypotheses were compared for both night and day situations under similar environmental conditions. The specific comparisons that were made and statistical tests that were performed are discussed in more detail in the following chapter.

In order to minimize any data bias, the observer was made as inconspicuous as possible. The exact technique, along with locational and procedural information, will be discussed in more detail in the following sections.

Data Collection Techniques Studied

There are two basic methods employed for conducting spot speed studies: one involves the measurement of time and distance, and the other uses the Doppler Principle. The time versus measured distance method was used for this research.

1. 20 - Pen graphic recorder. This type of timing unit, used primarily for research studies, was utilized extensively in the 1960's and 1970's by

engineering agencies. Since then, the video recording system has also been used. Due to the limited time available for data collection the video recording system was not used since it requires longer time to interpret the raw data.

In the early stages of the project the accuracy of the 20-pen recorder procedure was evaluated. The measured trap times were read to the nearest 1/10 of a second and were found to be precise within +/- 1.0 mph.(i.e., several runs were made by a vehicle traveling at a known speed along the speed traps). This figure supports the finding of other research using the 20-pen recorder.

The 20-pen graphic recorder normally is used in conjunction with pneumatic road tubes. Since pneumatic tubes are extremely conspicuous , drivers would be aware of their presence which could have an affect on their driving behavior and may distort the speed distribution. In an effort to minimize driver awareness, the 20-pin graphic recorder was actuated manually.

Equipment set-up. The 20-pen graphic recorder powered by a spring and pens attached to the signal control circuits by electrical wires were used to monitor the change in signal display. Two electrical wires with alligator clamps on each end connected the 20-pen recorder to 110 volt switches located inside the control box. One connection monitored the red signal indication and the

other monitored the amber signal indication for the approach phase. Great care was taken in hooking the clamps at the specific switch in order to prevent electric shock. A third connection was between the 20-pen and the observation point which actuated a 12 volt pen manually by impulses received from the observer approximately 330 feet away. Previous research found that traffic approaching a red display at a speed of about 40 mph didn't start to slow down until a point approximately 500 feet in advance of the signal.[7] Based on the above, temporary pavement tapes were placed on the pavement to mark the limits of the trap. A total of 5 speed traps were used, each with a length of 100 feet, with the exception of trap 1 which was measured at 62 feet. The boundary of trap 1 was at 38 feet from the traffic light in order to compensate for motorist abnormal stopping behavior, i.e., not all motorists stopped at the stop bar. (Figure 3.1). The minimal amount of tape was used in order to make the traps as inconspicuous as possible, while still serving the need of the observer. In an effort to minimize error resulting from parallax the observation point was located on top of a bank approximately 20 feet high and 30 feet away from the center of the road. The most important fact here is that the observation point is heavily wooded, enabling the observer to be as inconspicuous as possible, thereby minimizing his effect on observed speed values.

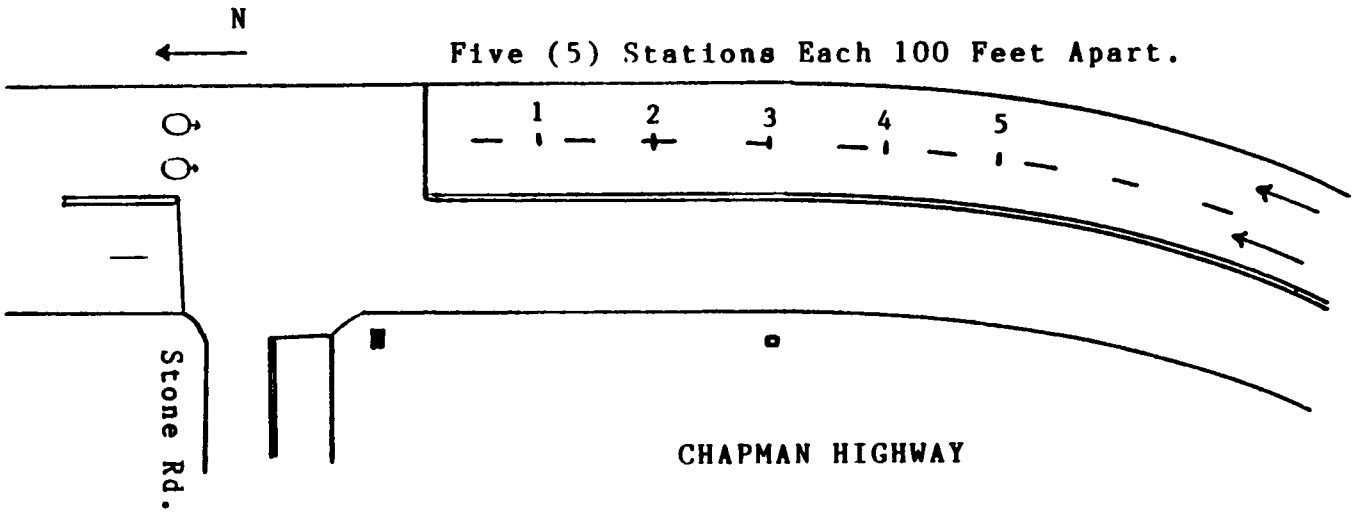


FIGURE 3.1. Study Approach.

Performance measures such as speed profiles and deceleration rates were interpreted and evaluated from raw data collected by the use of the 20-pen graphic recorder. The values were then tabulated and evaluated, and are presented in Chapter IV.

2. Stop watch method. The Perception - Reaction time of drivers approaching a traffic signal may increase with age, fatigue, alcohol, and physical deficiencies. Driver perception, as used herein, is defined as that time when the driver has the first opportunity to see the traffic light and realizes that he or she is approaching a red signal indication, and reaction time is that time required to apply the brakes after perception. As noted in Chapter II these intervals of time cannot be separated during field measurements.

Drivers view differ with respect to the eye height when seated. Figure 3.2 shows view from eye position of three drivers approaching a traffic signal with a child playing close to the edge of the road.[10] It is apparent that both the child and the traffic signal can be seen by the average driver, as shown in picture B, but neither the tall driver nor the short driver can see both, as shown in pictures C and A. In addition, the type of vehicle has an effect on the driver's view. Drivers in smaller cars may have lower eye height than drivers in larger cars. The

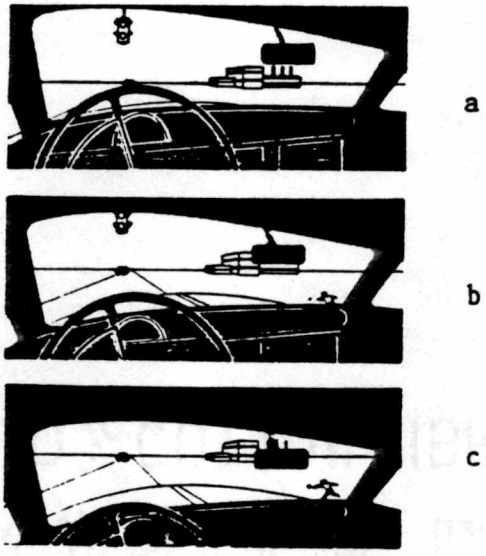


FIGURE 3.2. View From Eye Position of Three Drivers (5th, 50th, 95th Percentile in Height).

latter situation may enable drivers to see traffic lights earlier (i.e. if a vertical curve precedes the traffic light).

Today's highways are traveled by a wide variety of vehicles with a variety of driver's eye height; therefore a design value is used. The American Association of State Highway and Transportation Officials (AASHTO) states that "for all sight distance calculations, the height of the driver's eye is considered to be 3.5 feet above the road surface."[11] Based on the above, a 3.5 ft. driver's eye height was used to locate the initial point on the road where northbound drivers have the first opportunity to see the traffic light (Figure 3.3). Due to the geometry of the road studied, the center lane and the curb lane had different initial observation points. These points were carefully marked by temporary pavement tape (Figure 3.4). The minimum amount of tape was used in order to make the marks as inconspicuous as possible, while still serving the need of the observer.

Perception - Reaction time of drivers approaching a traffic signal is more helpful for traffic engineers if vehicles speeds are known. In searching for a technique that would measure both the speed of the vehicle and its driver's perception - reaction time, several selection criteria were established. First of all, the selected method had to be extremely inconspicuous. Secondly, it had

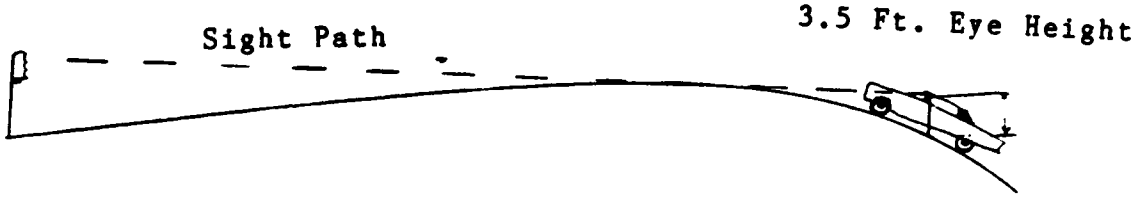


FIGURE 3.3. Driver's Eye Height.

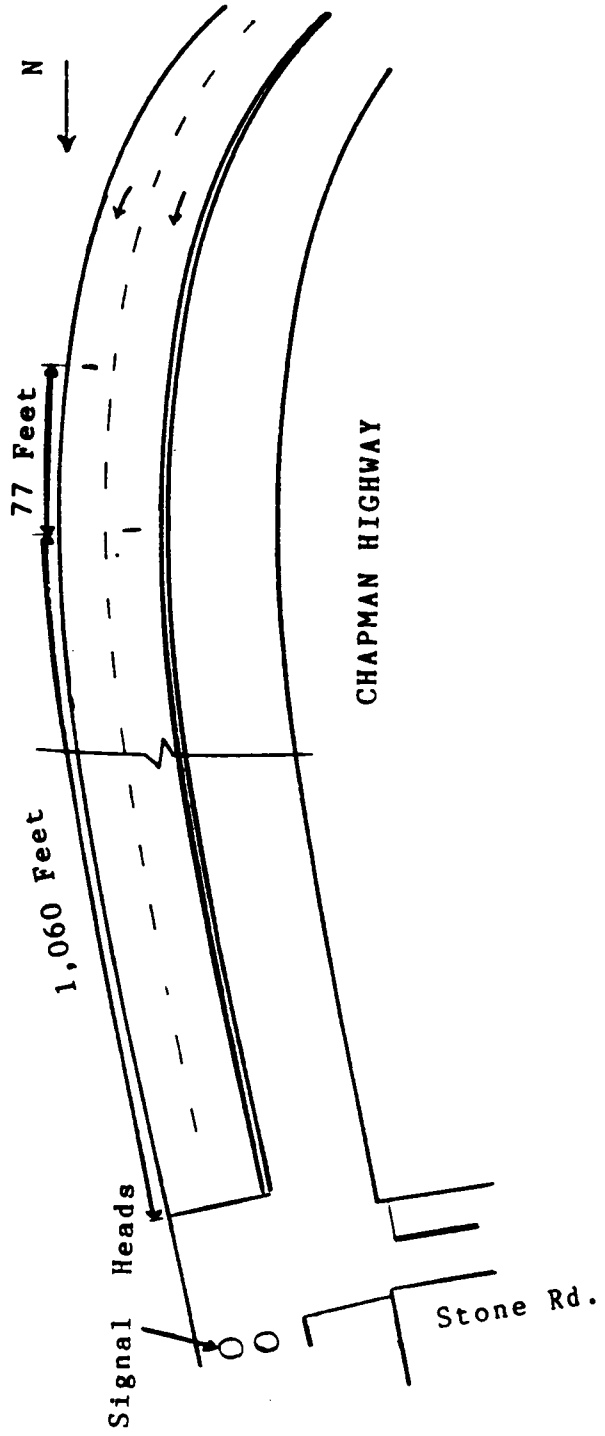


FIGURE 3.4. Initial Observation Points.

to be reliable and relatively simple to operate. And most important, it had to be operated by one person due to lack of manpower.

The data collection technique that was finally selected is probably the oldest of all speed measurement techniques. The two temporary pavement markings placed on the pavement to mark the point where drivers have the first opportunity to see the traffic light were used as limits of a trap, with a measured distance of 77 feet from boundary to boundary .

A digital electronic stop watch with lap time was used by the observer to time the vehicle through the speed trap and then again when the brakes were applied. It should be noted that vehicles with brake lights which did not burn were not included in the data set. A detailed comparison of the findings along with statistical interpretation is presented in the following chapters.

Both the 20-pen graphic recorder and the stop-watch used for data collection were actuated manually. Therefore, human errors were involved in the accuracy of the data collected. In order to minimize such errors, several steps were taken. First, the data were collected by one person, eliminating the different response from one person to another. Secondly, the data collection period did not extend beyond 2 hours on any day, minimizing the different reaction time of the observer resulting from

fatigue. It is difficult to fully eliminate all errors. But with the consistency in data collection, these errors should have minimal effect on the final comparison of the before and after conditions.

Study Location

A decision to test the strobe light at an urban signalized intersection was made after the performance measures and the data collection techniques were established and determined. This decision was narrowed down to a specific intersection after several considerations and observations of signalized intersections.

The following guidelines were established to facilitate the site selection process. First, the study location had to be within the city limits due to the willingness of Knoxville's Traffic Engineering Department to assist in this project. Secondly, the site needed to show a possible need for a strobe light. Third, it had a mix of local vs. non-local traffic. Fourth, it was important that the study location had an elevated area for an observation point with reasonable concealment the of observer.

The final study location that was chosen was a three-approach signalized intersection. The major street is Chapman Highway which is a 4 lane arterial and the minor street is Stone Road which is a 2 lane local road (Figure 3.5).

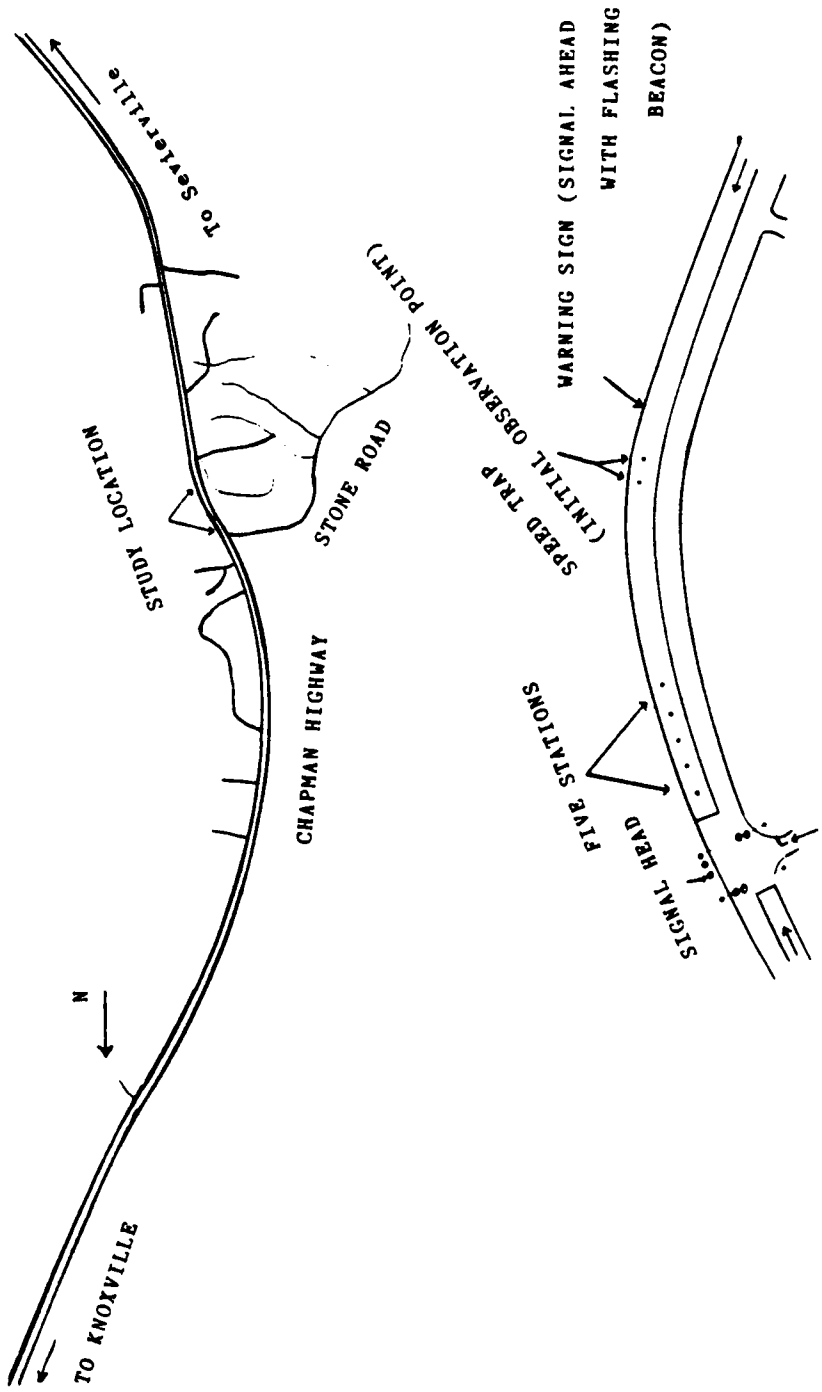


FIGURE 3.5. Study Location.

CHAPTER IV

STATISTICAL ANALYSIS AND PRESENTATION OF DATA

Introduction

The measures of effectiveness used in the evaluation of drivers performance at the study location are:

1. Deceleration Rates;
2. Speed Profile;
3. Perception - Reaction Time; and
4. Violations.

The measures of effectiveness are derived from raw data obtained from various data collection techniques and procedures which were discussed in the previous chapter.

The presentation of raw data along with statistical analysis regarding observed driver's performance measures and hypotheses testing are outlined below.

Analysis of Raw Data

Once the raw data were collected, it was necessary to condense it by statistical parameters in order to be analyzed and interpreted. Various statistical parameters can be used in the analysis of raw data, but the principal characteristics considered in this project are the frequency distribution, measure of central tendency, and measure of dispersion of values in the data set.

One of the steps employed in classifying and condensing these raw data was a frequency distribution. It is an arrangement in which different data points are combined in groups covering a specified range of values, such as 1 to 2, or 3 to 4 feet per second per second. The number of vehicles in each group is called frequency. Once these are established the frequency distribution curve is formed by plotting the percent of total observations versus the mean value of each group. Another step employed in condensing the raw data was the statistical measures of central tendency, and the more common ones are the arithmetic mean, median, and mode. Since the arithmetic mean is the abscissa of the centriod of the total area under the frequency curve which most describes the total data set, it was the mean that was selected for analysis in this research.[12]

The final step considered in classifying and condensing of data was the measure of dispersion by values of the data set. The most used measures were the variance, the standard deviation, and the range, which basically assigns a numerical value to the amount of spread by the values in the data set.[12]

The various statistical parameters discussed above were all employed in classifying and condensing these raw data, and were used in the evaluation of driver performance

measures at the specified study location for both the before and after condition.

Data collection used in the evaluation of driver's performance at the study location with a standard highway traffic signal (before study) was broken into two phases. The first phase which looked at deceleration rates and speed profiles of vehicles along the approach, started on November 19, 1987. A total of 133 and 64 vehicles were observed during the day and night respectively. The second phase which looked at perception -reaction time of drivers approaching the study location, started on November 27, 1987. A total of 160 and 77 vehicles were observed during the day and night respectively.

Data collection used in evaluating the traffic signal with strobe light (after study) was also broken into two phases. On December 14, 1987, approximately a week after the strobe was installed, data collection for the first phase began. A total of 138 vehicles were observed during the day and 64 vehicles were observed during the night. The second phase which looked at driver's perception - reaction time started on December 20, with a total of 160 and 78 vehicles observed during the day and night study respectively. Ideally, data collection for the after study should have started at least a month after the strobe light was installed, but due to the time limit on this project a period of one week was used.

The remainder of this chapter presents the results obtained, along with the statistical tests performed in the evaluating process.

Deceleration rates

Deceleration rate of vehicles at stations along the approach study were calculated from the equation $d = (V-Vo)/t$, which was discussed in Chapter II. Table 4.1 shows the various speeds and deceleration rates of a typical vehicle at the five speed traps (stations).

Average deceleration rates of vehicles approaching the intersection were expected to be lower after the installation of the white bar strobe. The greater conspicuity of the red lens with a strobe light,it was believed, would cause drivers to see the traffic light earlier and as a result slow down more gradually. Also it was expected that if differences did exist they would be lower at night due to the nature of this intersection (i.e. no strip development on either side of the approach which could distract drivers awareness of the traffic signal). Table 4.2 presents the average deceleration rates at stations for day and night conditions, which are also plotted in Figure 4.1. In order to determine if differences are significant from a statistical viewpoint, several tests were performed. The Chi-Square Goodness of Fit Test was used to check if the data collected could indeed be represented by a normal distribution. The test

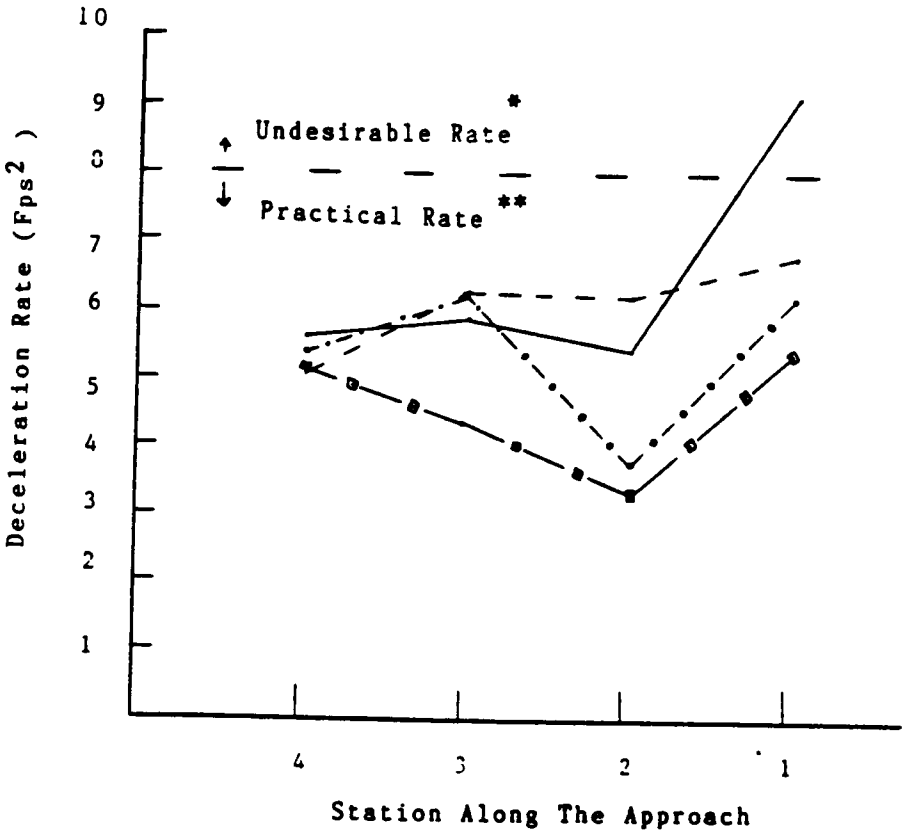
Table 4.1. Speed and Deceleration Rates of a Vehicle

At the various Stations.

STATION	ELAPSED TIME	SPEED (FPS)	SPEED (MPH)	CALCULATED TIME	DECELERATION RATE (FPSPS)			
5								
	1.6	62.5	42.6					
4				1.7	5.7			
	1.9	52.6	35.9					
3				2.0		3.5		
	2.2	45.5	31.0					
2				2.3			1.7	
	2.4	41.7	28.4					
1				2.5				7.5
	2.7	23.0	15.7					
0								

Table 4.2. Summary of Statistical Data for Day and Night Deceleration Rates

Station	1	2	3	4	1	2	3	4
	Day Before				Day After			
Sample Size	133	133	133	133	138	138	138	138
Standard Deviation	6.99	4.08	4.55	4.24	4.05	2.81	3.17	4.83
Mean	9.09	5.43	5.88	5.58	6.80	6.17	6.26	5.05
	Night Before				Night After			
Sample Size	64	64	64	64	64	64	64	64
Standard Deviation	6.87	3.16	3.34	6.41	4.98	2.50	3.07	4.91
Mean	5.33	3.33	4.35	5.07	6.19	3.74	6.22	5.36



* Deceleration Rate (8 to 11 fps^2)
** Deceleration Rate (< 8 fps^2)

(———) represents Day Before, (- - -) represents Day After,
(-■-■-) represents Night Before, (-•-•-) represents Night After.

FIGURE 4.1. Deceleration Rate Profile.

showed that this set of data was not normally distributed. Therefore, a nonparametric procedure proposed by W.H. Kruskal and W.A. Wallis that compares the means of continuous non-normal populations was used and is outlined below.[13]

The null and alternate hypotheses for the mean at the 0.05 and 0.01 level of significance are given below:

Null Hypothesis (Mean at each station for day and night)

Ho: Xb ≠ Xa

There is a significant difference between means.

Alternative Hypothesis (Mean at each station for day and night)

H1: Xb = Xa

There is no significant difference between means.

The results of the Kruskal - Wallis test for the day condition as shown in table 4.3, indicates a significant decrease at station 1, located 100 feet away from the stop bar, at the 95% confidence level. It also indicates that there is no significant difference at the other stations at both the 95% and 99% confidence levels. Also, the results of the Kruskal - Wallis test for the night condition as shown in table 4.4, indicates no significant difference at stations 1, 2, and 4 at both the 95% and 99% confidence level. However, there is a significant increase at station 3 in the after study.

Table 4.3. Results of Kruskal - Wallis test for Day Deceleration Rates

Station	h Calculated	df	X^2 0.05	Result	X^2 0.01	Result
4	0.65	1	3.841	Reject Ho	6.635	Reject Ho
3	1.65	1	3.841	Reject Ho	6.635	Reject Ho
2	3.33	1	3.841	Reject Ho	6.635	Reject Ho
1	6.23	1	3.841	Accept Ho	6.635	Reject Ho

Ho: Xa ≠ Xb

Table 4.4. Results of Kruskal - Wallis test for Night Deceleration Rates

Station	h Calculated	df	X^2 0.05	Result	X^2 0.01	Result
4	0.28	1	3.841	Reject Ho	6.635	Reject Ho
3	13.58	1	3.841	Accept Ho	6.635	Accept Ho
2	0.74	1	3.841	Reject Ho	6.635	Reject Ho
1	0.00	1	3.841	Reject Ho	6.635	Reject Ho

Ho: Xa ≠ Xb

Speed Profiles

The average speed of vehicles approaching the intersection may or may not be different after the installation of the h'ghway traffic signal with strobe. Ideally, the average speeds should be lower at entry station (Station 5) after the installation of the strobe light because drivers should be aware of the red traffic signal sooner and slow down earlier. However, if there was a change in speed, it may not be large enough to be statically significant.

Figures 4.2 and 4.3 shows speed profiles for solo vehicles along the approach in each of the before and after conditions for both day and night respectively. Each point is an average speed between two stations and is plotted at the mid-point of each trap. A vehicle was considered solo for the purpose of this analysis on the following two conditions. First, it penetrates station 5 and the signal display is red. Secondly, there is no car in advance of it for at least 300 feet. Thirdly, it makes a complete stop before the signal display changes to green.

The following remarks are made concerning the average speed profiles for the before and after situations. First, the average speed during the day was approximately 50 mph at station 5 for both the before and after situations. Secondly, the largest speed change during the day occurred between 69 feet and 150 feet upstream from the

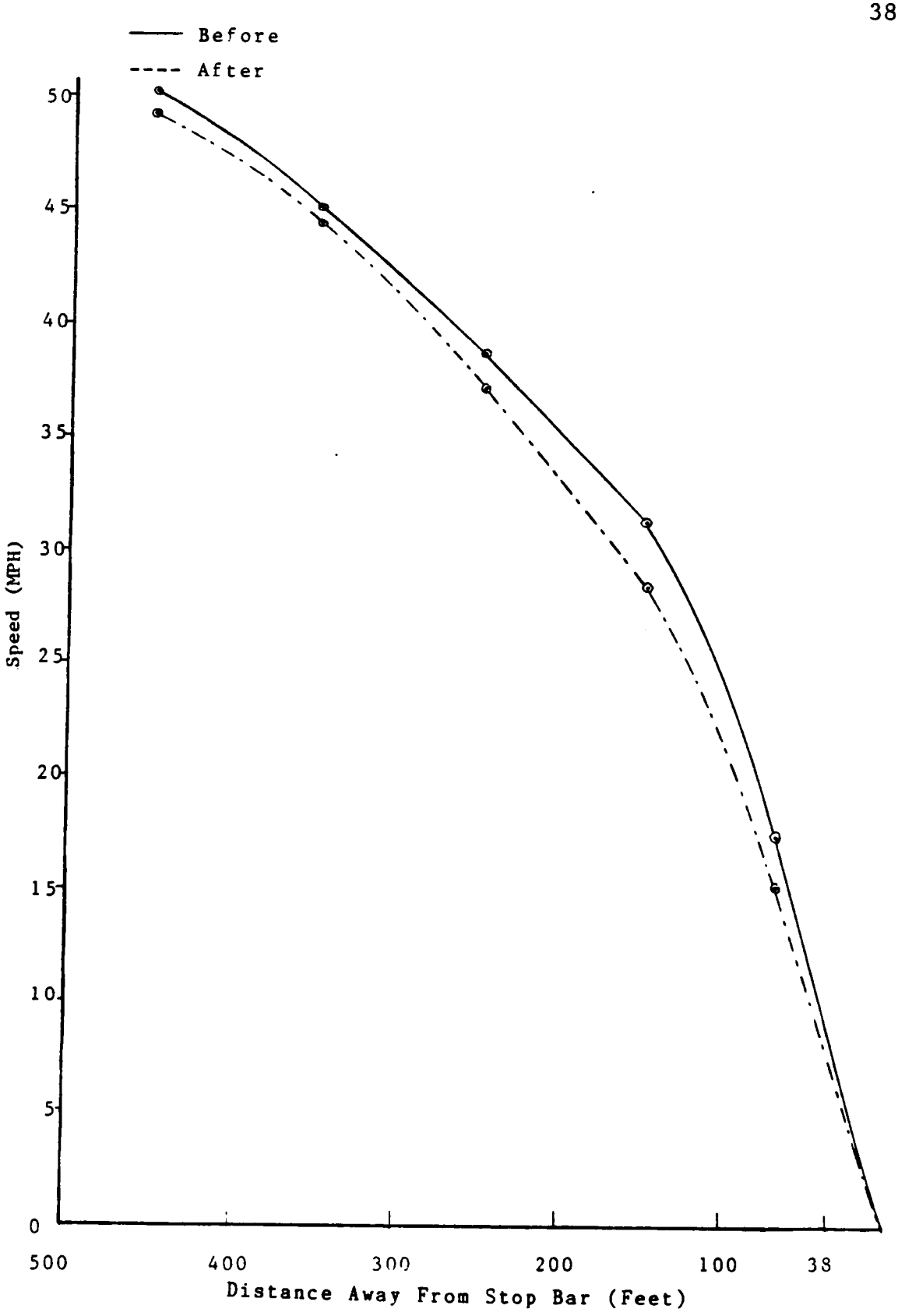


FIGURE 4.2. Speed Profile - Day.

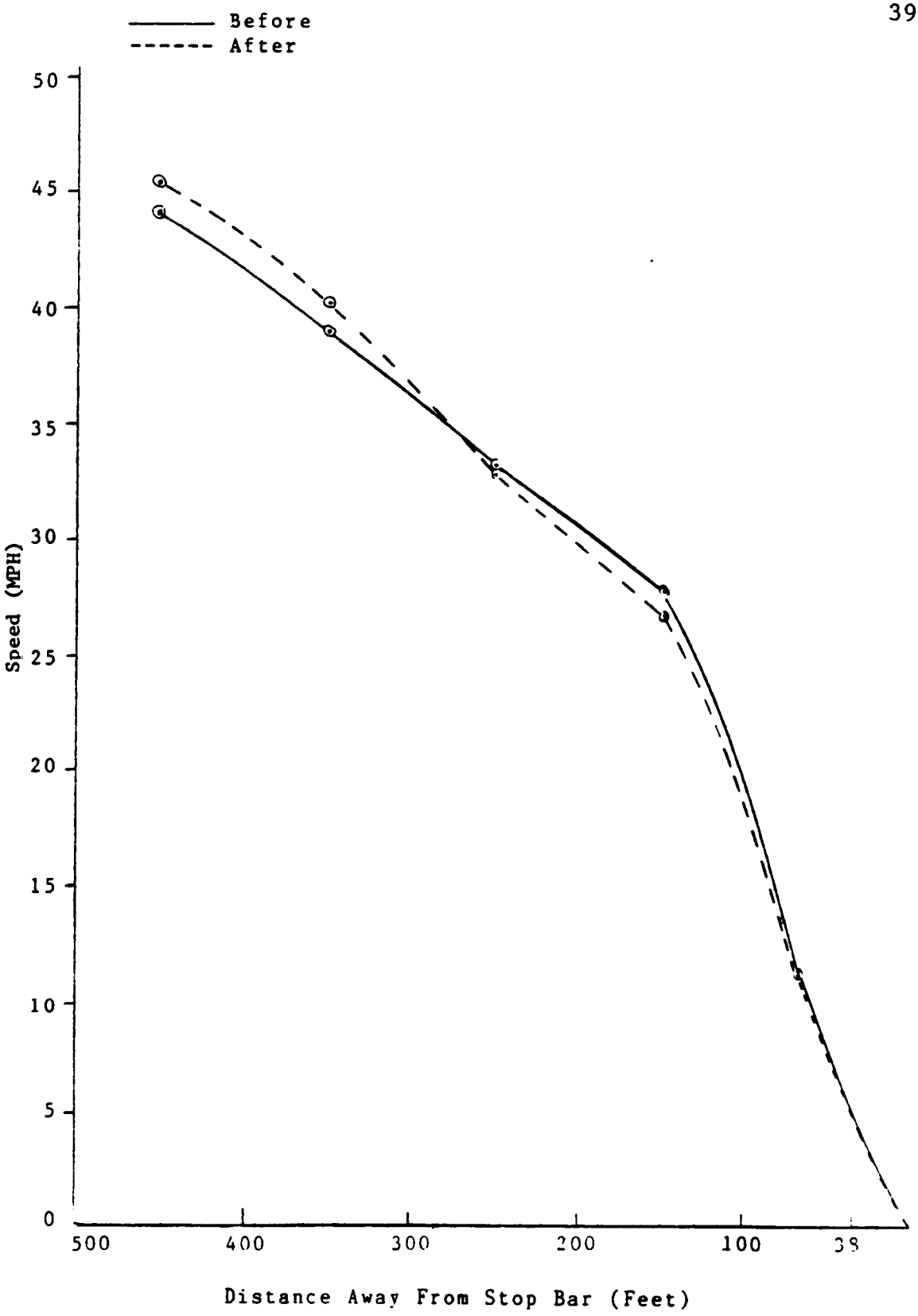


FIGURE 4.3. Speed Profile - Night.

stop bar, with a 13.9 mph speed reduction for the before condition and 13.2 mph for the after condition. Thirdly, the average speed between stations 1 and 2 decreased after the installation of the strobe light approximately 3 mph during the day and 1 mph during the night.

Even though a change of 3 mph is not significant from a statistical viewpoint, it may be significant from a practical viewpoint. Finally, it is interesting to note that drivers during the night penetrated the study area at about 5.5 mph slower than during the day.

Violations

Violations of vehicles approaching a signalized intersection was defined according to the National Committee on Uniform Traffic Laws and Ordinances[14] as stated below:

> Vehicular traffic facing a steady circular red signal alone shall stop at a clearly marked stop line, but if none, before entering the crosswalk on the near side of the intersection, or if none, then before entering the intersection and shall remain standing until an indication to proceed is shown.

The results obtained during the use of the 20-pen recorder showed that no violations were committed at this intersection for either the existing traffic signal or the traffic signal with the strobe light. However, this was not unusual due to the limited amount of data available.

Perception - Reaction Time

As discussed in the previous chapters, the driver's perception -reaction time for this study, was defined as the difference in time when a driver had the first opportunity to see the traffic light and the illumination of the brake lights. It was hypothesized that perception - reaction time would be lower after the installation of the strobe light due to the added conspicuity of the traffic light. It was also expected that the presence of stopped cars at the traffic light would cause drivers to be aware of the traffic light earlier and react faster due to the added stimuli of their illuminated brake lights.

Due to the limited amount of data available, perception - reaction times were broken into only two groups. The first group was for vehicles with approach speed $\leq$ 50 mph, and the second group was for vehicles with approach speed $>$ 50 mph. Furthermore, each group was analyzed for whether or not vehicles were stopped at the traffic light when the observed vehicle penetrated the initial observation point. The mean values of Perception-Reaction times were plotted and are shown in Figures 4.4 and 4.5. The Figures indicate that drivers applied their brakes quicker after the installation of the strobe light for both day and night conditions.

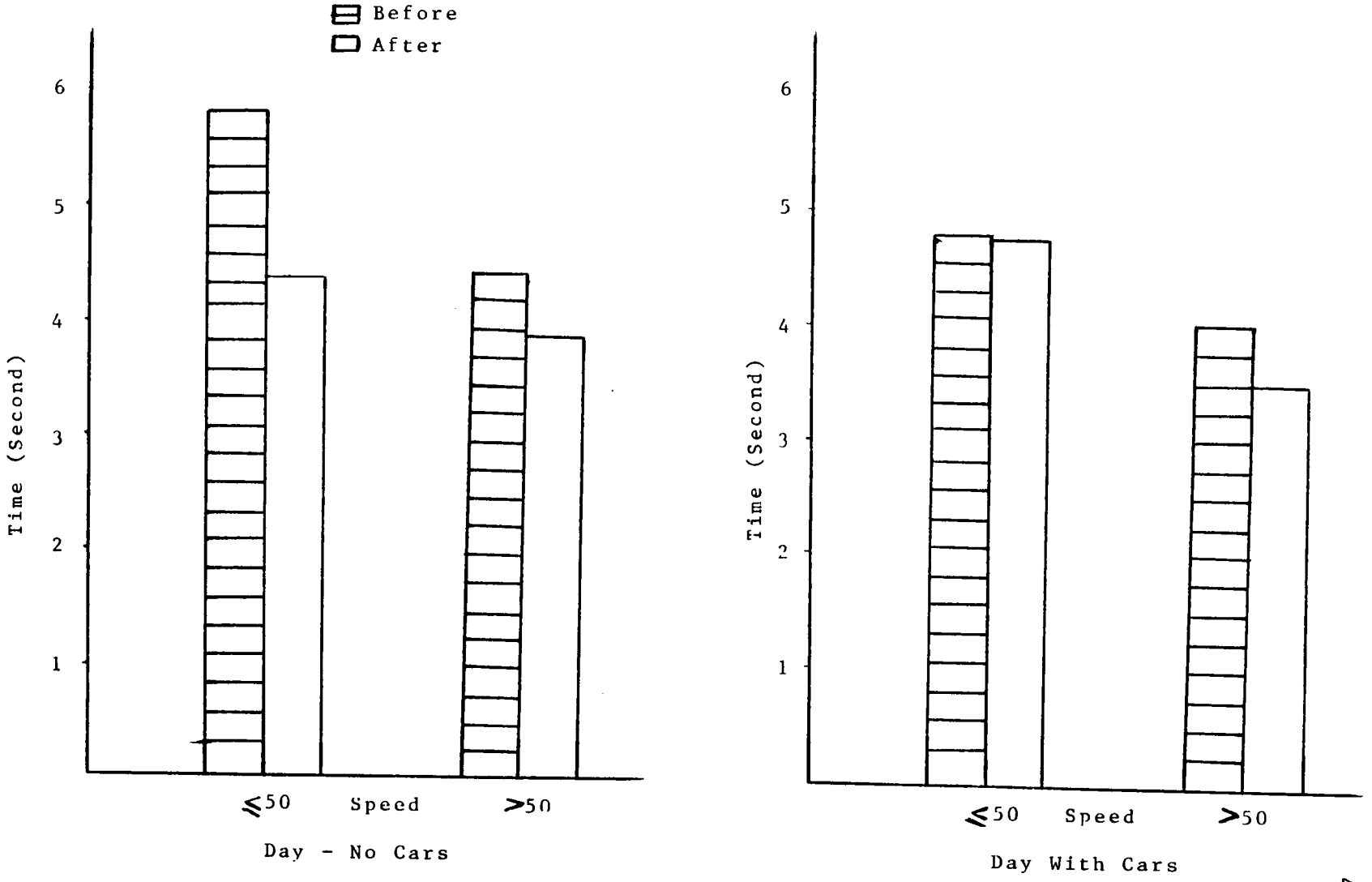


FIGURE 4.4. Driver's Perception - Reaction Time (Day).

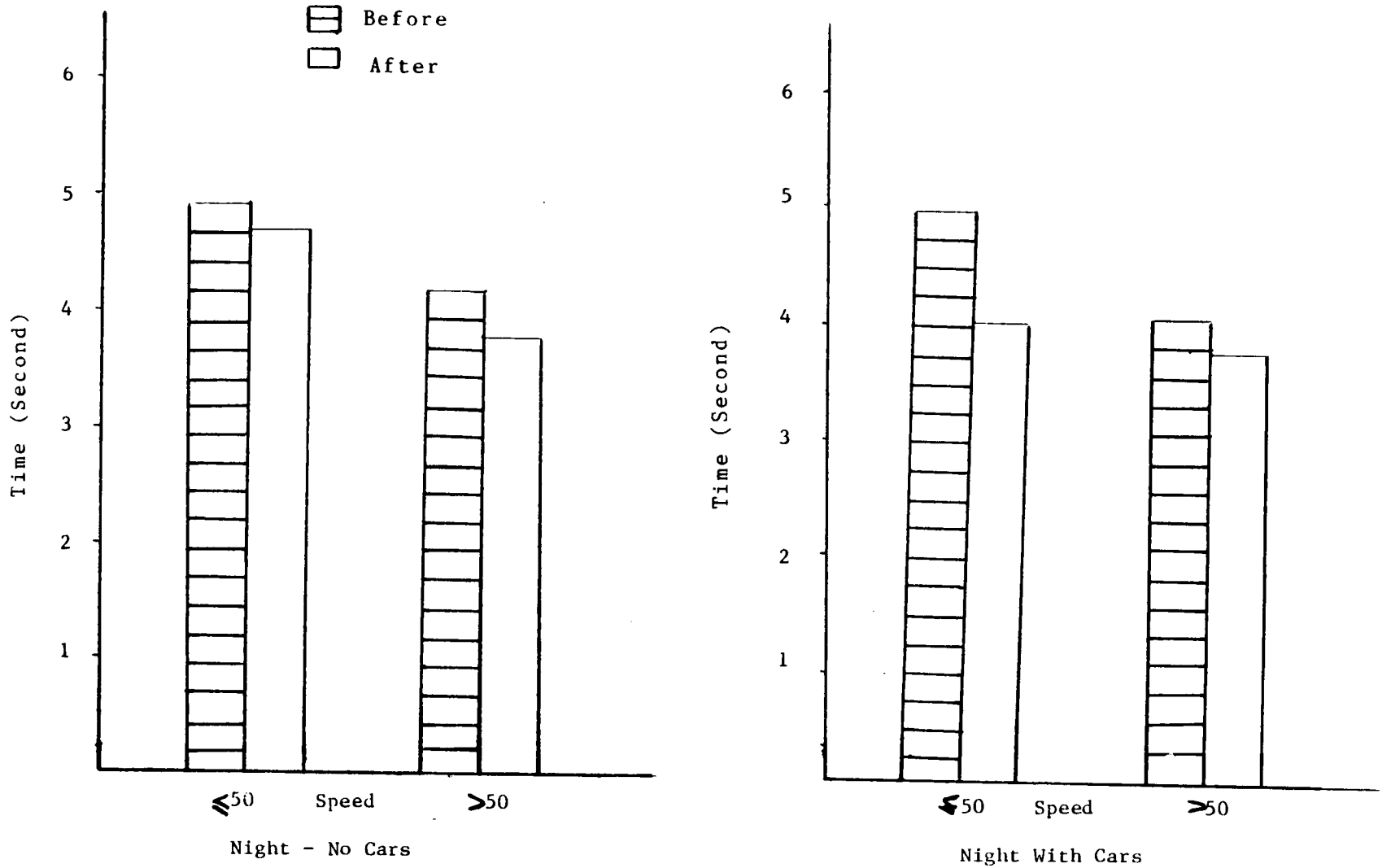


FIGURE 4.5. Driver's Perception - Reaction Time (Night).

Tables 4.5 and 4.6 presents statistical summaries of Perception - Reaction times. As seen from Table 4.5 driver reaction times were approximately 11%, 26%, and 28% lower for different groups.

In order to determine if these changes are statistically significant the following tests were performed.

The t-Test was performed to determine if the "before" and "after" mean values are significantly different at the 0.05 and 0.01 level of significant.

The null hypothesis tested was:

$$Ho: Xa \neq Xb$$

which states that the two population means were not equal

The alternative hypothesis was:

$$Hl: Xa = Xb$$

which states that the two population means were equal.

The use of the t-Test involves the assumption of equivalent variances. Therefore, before preceding with the t-Test, it was necessary to determine if the variances of each group were equal or not. The equality of the variances was determined by the F-Test.

The null hypothesis tested was:

$$Ho: \sigma_a^2 = \sigma_b^2$$

which states that the variances were equal.

Table 4.5 Summary of Statistical Data for Day Perception - Reaction Times

Speed	< 50 MPH Before	< 50 MPH After	% Change	> 50 MPH Before	> 50 MPH After	% Change
No Cars						
Sample Size	13	7		31	27	
Standard Deviation	2.64	2.85		2.02	1.64	
Mean (Sec.)	5.80	4.30	26	4.40	3.90	11
Rang (Sec.)	1.5-9.0	1.2-8.9		1.6-11.2	0.9-7.2	
With Cars						
Sample Size	38	27		78	96	
Standard Deviation	2.50	2.70		1.75	1.77	
Mean (Sec.)	4.81	4.80	0	4.87	3.50	28
Rang (Sec.)	1.3-11.1	0.2-10.1		1.3-8.9	0.1-7.1	

Table 4.6 Summary of Statistical Data for Night Perception - Reaction Times

Speed	< 50 MPH Before	< 50 MPH After	% Change	> 50 MPH Before	> 50 MPH After	% Change
No Cars						
Sample Size	15	7		14	9	
Standard Deviation	2.21	2.14		1.96	2.32	
Mean (Sec.)	4.90	4.70	4	4.20	3.80	9
Rang (Sec.)	2.1-9.2	2.6-8.8		2.0-9.0	0.9-8.0	
With Cars						
Sample Size	20	28		29	33	
Standard Deviation	1.91	1.64		2.29	1.98	
Mean (Sec.)	4.90	4.00	18	4.00	3.80	5
Rang (Sec.)	2.0-8.4	0.9-6.7		0.7-8.1	0.9-9.1	

The alternate hypothesis was:

H1: $\sigma_a^2 = \sigma_b^2$

which states that the variances were not equal.

The F-Test showed that the data used by the t-Test had equal variances therefore the t-Test was valid. The t-Test and the F-Test were performed separately for the day and night condition at the 0.05 and the 0.01 levels of significance as shown in Tables 4.7 and 4.8.

Even though there was a difference in the driver's perception - reaction time, i.e. quicker response time as shown on Figures 4.4 and 4.5, these differences were not statistically significant for conditions 1 (no cars with speeds < 50 mph), 2 (no cars with speeds > 50 mph), and 3 (with cars and speeds < 50 mph), at the 0.05 and 0.01 levels of significance. However, there was a statistically significant decrease for the fourth condition (cars stopped with speeds > 50 mph) at the 0.05 level of significance for both the day and night observations.

The t-Test used in evaluating Perception-Reaction times also assumes that the data collected for this study were taken from a population exhibiting a normal distribution. In order to test this assumption, the Chi-Square Goodness of Fit Test was applied to the data set to verify the normality of the population.

Table 4.7. Results of t-Test and F-Test for Day Condition

Perception - Reaction Times

Condition	F-Test* Calculated	Tabulated Value	Result	t-Test** Calculated	Tabulated Value (0.05)	Result	Tabulated Value (0.01)	Result
1. No Cars with Speeds ≤ 50 mph	1.16	2.33	Accept Ho	1.20	1.73	Reject Ho	2.55	Reject Ho
2. No Cars with Speeds > 50 mph	1.52	1.68	Accept Ho	1.02	1.68	Reject Ho	2.42	Reject Ho
3. With Cars and Speeds ≤ 50 mph	1.17	1.62	Accept Ho	1.28	1.67	Reject Ho	2.39	Reject Ho
4. With Cars and Speeds > 50 mph	1.02	1.34	Accept Ho	2.12	1.65	Accept Ho	2.35	Reject Ho

* Ho : $\sigma^2_a = \sigma^2_b$

** Ho : $X_a \neq X_b$

Table 4.8. Results of t-Test and F-Test for Night Condition

Perception - Reaction Times

Condition	F-Test* Calculated	Tabulated Value	Result	t-Test** Calculated	Tabulated Value (0.05)	Result	Tabulated Value (0.01)	Result
1. No Cars with Speeds ⩽ 50 mph	1.07	2.87	Accept Ho	0.26	1.72	Reject Ho	2.53	Reject Ho
2. No Cars with Speeds > 50 mph	1.40	2.12	Accept Ho	0.49	1.72	Reject Ho	2.52	Reject Ho
3. With Cars and Speeds ⩽ 50 mph	1.44	1.69	Accept Ho	1.45	1.68	Reject Ho	2.40	Reject Ho
4. With Cars and Speeds > 50 mph	1.46	1.61	Accept Ho	1.82	1.67	Accept Ho	2.39	Reject Ho

* Ho : $\sigma^2_a = \sigma^2_b$

** Ho : Xa ≠ Xb

The value of the Chi-Square was calculated as

$$\lambda^2 = \sum_{n=1}^{k} \frac{(f_o - f_t)^2}{f_t}$$

where f_o = observed frequencies
f_t = theoretical frequencies
k = number of speed groups

This value was then compared to a tabulated value of chi-square for a desired level of significance to determine if the data collected represents a normal distribution.

The null hypothesis tested was:

Ho : Xa = Xb

which states that the data was normally distributed.

The alternative hypothesis was:

H1 : Xa ≠ Xb

which states that the data was not normally distributed. Table 4.9 summarizes the results of these test (See next page).

Table 4.9 Results of Chi-Square Test for Normality

Perception - Reaction Times

* Condition	X^2 Calculated	X^2 0.05	Result
Day Before (No Cars)	4.54	12.59	Accept Ho
Day After (No Cars)	1.27	11.07	Accept Ho
Day Before (With Cars)	0.93	14.07	Accept Ho
Day After (With Cars)	6.89	12.59	Accept Ho
Night Before (No Cars)	1.63	9.49	Accept Ho
Night After (No Cars)	0.02	5.99	Accept Ho
Night Before (With Cars)	2.97	12.59	Accept Ho
Night After (With Cars)	0.66	11.07	Accept Ho

*Ho : Xa = Xb

The results of the Chi-Square Test shows that the null hypothesis is accepted for all conditions. Therefore, the assumption made by the t-Test that the data are normally distributed is quite reasonable at the 0.05 and 0.01 levels of significance.

In summary, table 4.10 outlines the differences observed for corresponding mean values during the before and after study.

Table 4.10. Summary of Data Analysis

	Day				Night			
	Before	After	Statistically Significant (0.05)	Change (%)	Before	After	Statistically Significant (0.05)	Change (%)
Deceleration Rates								
Station 1	9.09	6.8	Yes	25	5.33	6.19	No	-14
Station 2	5.43	6.17	No	-12	3.33	3.74	No	-11
Station 3	5.88	6.26	No	- 6	4.35	6.22	Yes	-30
Station 4	5.58	5.05	No	10	5.07	5.36	No	- 5
Speed Profiles								
Station 1	31.6	28.7	No	9	27.8	26.6	No	4
Station 2	38.9	37.4	No	4	33.2	32.7	No	2
Station 3	45.2	44.5	No	2	38.8	40.1	No	- 3
Station 4	50.3	49.4	No	2	44.0	45.2	No	- 3
Perception - Reaction Times								
Speed $\leq$ 50 mph								
No Cars	5.8	4.3	No	26	4.9	4.7	No	4
With Cars	4.8	4.8	No	0	4.9	4.0	No	18
Speed > 50 mph								
No Cars	4.4	3.9	No	11	4.2	3.8	No	9
With Cars	4.87	3.5	Yes	28	4.0	3.8	Yes	5

CHAPTER V

CONCLUSION

Two data collection techniques were selected for this study of the driver performance at a signalized intersection. Data obtained using the 20-pen recorder were used to determine the change in deceleration rates and speed profiles along the approach. A stop-watch was used to measure driver's Perception - Reaction Time to a red signal indication. The previous chapters outlined the purpose of this study, measures of effectiveness used in evaluating driver's performance, data collection techniques studied, and the statistical analysis used. Final conclusions from this study are shown below.

Daytime Deceleration Rates

Deceleration rates at station 1 had decreased from 9.09 Fps^2 to 6.8 Fps^2 after the installation of the strobe light. This decrease was found to be statistically significant at the 95% confidence level. Furthermore, this decrease at station 1 had lowered the deceleration rate from an "undesirable level" to a "practical level" as defined by the Traffic Engineering Handbook (the point at which this deceleration occurred being 100 feet from the traffic light). It should be emphasized that such a decrease in deceleration rates at only 100 feet from the traffic light is defiantly desirable and should result in

less accidents. The before and after deceleration rates at stations 2, 3, and 4 (200, 300, and 400 feet from the traffic light) were found to have no statistically significant differences.

Nighttime Deceleration Rates

Deceleration rates at all stations during the nighttime study were in the practical range (less than 8 fps^2) for both the before and after study. Furthermore, there were no significant changes in nighttime deceleration rates at stations 1, 2, and 4. Surprisingly an increase in the deceleration rate was apparent after the installation of the strobe light at station 3 approximately 300 feet from the traffic light. This increase was statistically significant at the 95% confidence level, nevertheless deceleration rates during the night were all below 6.22 fps^2, which is in the practical level.

Speed Profiles

The speed profiles for both day and night conditions had failed to indicate a statistically significant change. However, this finding was not unexpected considering the limited amount of data. From the practical viewpoint, vehicle speed profiles during the day did show a decrease in speed at all stations along the approach.

Perception - Reaction Time

The results from this study showed that the driver's perception-reaction time was lower after the installation of the strobe light for both day and night conditions. Drivers did apply their brakes quicker in the case with the strobe light. As a result, a 26% reduction was apparent during the day for vehicle speeds less than 50 mph (which is the speed limit) when no cars were stopped at the traffic light. However, this change in perception-reaction time was not found to be statistically significant at the 0.05 confidence level. In the case of speeds greater than 50 mph with vehicles stopped at the traffic light, there was a statistically significant reduction in speed at the 0.05 confidence level. During night time condition the perception - reaction time was not found to be statistically significant, regardless of speech or the presence or absence of other vehicles.

Violations

The results from this study showed that from the approximately 400 vehicles observed both during the before and after study, not one car penetrated the intersection while the signal display was red.

In summary, this study showed that the installation of a strobe light at this intersection, where it was difficult to discern the traffic signal because of road geometrics, was helpful in drawing the driver's

attention to the red signal indication. Such a display did enable many drivers to apply their brakes earlier and make a safer and more gradual approach to the traffic signal.

The results showed that the driver's perception-reaction time was lowered in the range of 26 to 28 percent during day time operation. Because drivers were able to react to the red indication earlier they were able to come to a safer and more gradual stop. Furthermore, this study showed a 25% reduction in daytime deceleration rates at station one, which was located one hundred feet away from the stop bar. This reduction was significant due to the fact that most rear end accidents at signalized intersections occur close to the intersection. Here the deceleration rate was reduced from an "undesirable level" to a "practical level" as defined by The Traffic Engineering Handbook. The fact that the differences in deceleration rates during the nighttime condition were not as impressive, might be explained by the fact that at this location there was no strip development which could distract driver's awareness of the red indication. Hence, there was little light clutter at the intersection and the red indication quickly caught the driver's attention.

The red signal section lens with the strobe cost approximately 210 dollars in 1984. Today the cost is approximately 575 dollars. For this increase in cost of 300 to 600 dollars on a signal installation costing 35,000

to 60,000 dollars, the strobe light warrants further study to define effectiveness and most advantageous location. Additional intersections need to be studied to indicate those locations where strobe lights reduces perception-reaction time and deceleration rates. For example, intersections that have geometric problems, i.e., making it difficult for motorist to see the red indication. And intersections that have strip development which may distract drivers awareness of the traffic signal. In addition to the above, the strobe light needs to be evaluated in cases where new signals are installed, and at the first signal encountered by motorist approaching an urban area. Also, the strobe light needs to be evaluated in cases where signals are closely spaced. An example of such a location is the intersection at Kingston Pike in front of the Walker Springs Shopping Center. Westbound motorists on Kingston Pike could be temporarily confused as to which of the two signal light comes first, this is partly caused by road geometrics. Furthermore, there is a need to study the effect of the strobe light on motorist if installed in one or two of the signal heads.

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VITA

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Mr. Ghezawi is a member of the Institute of Transportation Engineers, American Association of Civil Engineers, and Jordanian Engineering Association. He plans to go back to Jordan and work with the Amman Municipality.