Chapter 4 Data Analysis

4.1 Testing of Speed Data

Speed data collected from a moving traffic stream in stable flow generally follows a normal distribution. In order to ensure the validity of the speed data collected in this research effort, and the validity of the subsequent statistical analyses, the collected data was tested to check for conformity with a normal distribution. All of the speed data sets were tested using standard chi-square testing procedures to test for conformity with the normal distribution at a ninety-five percent confidence level. The results of these tests indicated that the assumption that the measured speeds are normally distributed is valid. The details of the testing procedure, and its results, are found in Appendix C.

4.2 Statistical Analysis of Data

The speed data collected for this effort must conform to a normal distribution for the statistical analyses to be performed. Changes in the measures of effectiveness between station 1 and station 2 will be tested for statistical significance. For mean speed, differences between the control condition (no speed control) and the treatment condition (speed control technique applied) in the changes between stations will also be analyzed. This analysis will isolate the effects of the speed control technique from other factors present (such as signage approaching the work zone) that may affect traffic.

4.2.1 Changes in Mean Speed

Sample sizes are sufficiently large for testing the speed changes among several sectors of the population. Mean speed changes for all traffic, for cars, for trucks, and for traffic exceeding the speed limit (in terms of speed at station 1) can be analyzed. A similar analysis of the fastest fifteen percent of traffic (those exceeding the eighty-fifth percentile speed) was considered but ruled out for statistical reasons, as will be discussed later in this section. In this section, tests for significant differences will be performed on the change in mean speed between station 1 and station 2 for each condition for all vehicles, for cars, for trucks, and for the top fifteen percent. The difference between control and treatment conditions in mean speed change, for each of the above groups, will then be examined.

Table 4.1 presents speed data for all conditions studied, for all traffic, cars, and trucks. Mean speeds of the sector of the traffic stream exceeding the speed limit are not presented, as the mean of a portion of a normal distribution is not useful. However, the speed changes between stations, and between control and treatment conditions, of this sector are relevant in that these drivers are the ones who are not complying with traffic regulations. Since the faster that a vehicle is traveling, the greater the forces exerted upon impact are (in the case of an accident), these vehicles comprise a key target sector of the population in the use of speed control techniques.

For analysis of changes in mean speed between station 1 and station 2 for a given condition set, a one-sample *t* test is used (23). The null hypothesis is that the mean speeds at each station are equal, or that no statistically significant difference exists between them. The *p* value ascertained from the *t* distribution critical values table indicates the probability of obtaining data at least as extreme as that actually observed when the null hypothesis is assumed true. Therefore, if this probability is very small, then our null hypothesis is unlikely given the observed data, and it is rejected. The value of *t* is calculated as follows:

$t = V / (s / n^{0.5})$ where (2)

V = mean change in speed between station 1 and station 2

s = standard deviation of mean change in speed

n = sample size

and *t* has a *T*-distribution with *n-1* degrees of freedom under the null hypothesis

The resulting t value was then checked against the t distribution critical values table to determine the corresponding p value, denoting the level of significance of the change. The t and p values, along with the change in mean speed between stations for each speed control condition, are listed in Table 4.2. A value of p less than 0.05 indicates that the difference considered is significant, while a value of less than 0.01 corresponds to a highly significant difference. Values of p greater than 0.10 are marked with ‘ - ’ , as they would be indicative of differences far short of being statistically significant. It can be seen from the table that for each treatment condition, highly significant reductions in the mean speed of the entire traffic stream were experienced from station 1 to station 2. Thus, the null hypothesis can be confidently rejected.

Further inspection of the data reveals interesting observations about the speed changes. The control conditions at site 2 also caused highly significant reductions in mean speed. The speed reductions that occurred at this site in the control studies may be attributable to the combined effects of many factors. The work zone at this site had been in the same configuration almost continuously for about three months when the studies were conducted, and police enforcement was typically present at this site during the day. This site also has a relatively high proportion of peak period commuter traffic. Given the familiarity that most drivers had with the site and the expectations they may have had concerning enforcement, traffic speeds decreased significantly entering the work zone even without a speed control technique present. When cars and trucks are considered separately, some interesting results of the hypothesis testing are also noted. At site 1B, the mean speed reduction among cars in the treatment condition fell short of being statistically significant, with a p value between 0.05 and 0.10 (approximately 0.08).

To isolate the effects of the drone radar on mean speed, the difference between the mean speed change from station 1 to station 2 for the control condition and the corresponding treatment condition must be considered. A pooled two-sample t test for comparison of two means is applied (23). In this situation, the null hypothesis is that the mean speed changes for the two conditions are equal. The value of t is calculated as follows:

$$t = (V_{treat} - V_{ctrl}) / s_p \; [(1 / n_{treat}) + (1 / n_{ctrl})] \text{ where} \qquad (3)$$

V_{treat} = *mean speed change between stations 1 and 2 for treatment condition*

V_{ctrl} = *mean speed change between stations 1 and 2 for control condition*

n_{treat} = *sample size of treatment data set*

n_{ctrl} = *sample size of control data set*

$s_p^{\,2} = [s_{treat}^{\,2} (n_{treat} - 1) + s_{ctrl}^{\,2} (n_{ctrl} - 1)] / (n_{treat} + n_{ctrl} - 2)$

s_p = *pooled standard deviation*

s_{treat} = *standard deviation of mean change in speed for treatment condition*

s_{ctrl} = *standard deviation of mean change in speed for control condition*

and t has a T-distribution with $n_{treat} + n_{ctrl} - 2$ degrees of freedom under the null hypothesis

As with speed changes for a particular condition, the resulting t value was then checked against a t distribution critical values table to determine the corresponding p value, denoting the level of significance of the change. The t and p values for each speed control technique are listed in Table 4.3. A value of p less than 0.05 indicates that the difference considered is significant, while a value of less than 0.01 corresponds to a highly significant difference. Values of p greater than 0.05 are marked with ‘ - ’ , as such values indicate that no significant differences in mean speed change occurred for those particular treatments (speed control techniques). It can be seen from the table that at sites 1A, 1B, and 3, the null hypothesis can be rejected at the ninety-five percent confidence interval, as the respective values of p for the differences in speed changes are less than 0.05.

As with the hypothesis testing on mean speed changes for a given speed control condition, it is interesting to examine the speed patterns at site 2. It can be seen from Table 4.3 that the speed control techniques applied at site 2 did not create significant differences in mean speed changes when compared with the control (no speed control technique) conditions. The fact that speed control techniques did not create significant reductions in addition to those that occurred when no speed control was in place may be due to drivers' expectations of enforcement at this work zone, as described on the preceding page. At site 2A, where a police vehicle was stationed immediately upstream of the shoulder closure, and site 2B, in which the only difference was placement of the drone radar unit where the police car had been, nearly identical reductions in mean speed were observed. This supports the suggestion that periodical substitution of drone radar for police presence, in work zones with regular enforcement, maintains speed reduction patterns.

Traffic volume may be a factor in the extent of the change in mean speed of traffic in response to speed control techniques. The data in this study were collected so that such an examination could be made. However, an inspection of the data indicates that no apparent relationship exists between traffic flow and mean speed change in response to the speed control techniques applied.

4.2.2 Changes in Speed Variance

Reduction in speed variance, as well as in mean speed, improves safety and lowers the probability of an accident. Examination of the changes in standard deviation, as a measurement of the variance in speeds, can also be done through hypothesis testing to test for statistically significant differences. Table 4.4 presents the standard deviation of speed at each station for each speed control condition studied, for all traffic, cars, and trucks. With standard deviation of speeds, the entire population, and the car and truck sectors, will be examined. The null hypothesis is that the variances at station 1 and station 2, for a particular speed control condition, are the same. This null hypothesis can be tested using the *F*-statistic, which is essentially a ratio of the variances at each station, fixed to be greater than unity (23). It is calculated as follows:

$$F = s_a^{\,2} \ / \ s_b^{\,2} \quad \text{where} \tag{4}$$

$s_a^{\,2}$ = *the higher of the variances (standard deviation squared) at either station*

$s_b^{\,2}$ = *the lower of the variances (standard deviation squared) at either station*

and F has an F-distribution with $n_a + n_b - 2$ degrees of freedom under the null hypothesis

The resulting F value, for a given comparison and degrees of freedom, is checked against an F critical values table to determine the corresponding value of p and the corresponding level of significance of the change in variance. The results of the hypothesis testing on speed variance are presented in Table 4.5, which lists the change in standard deviation between observation stations 1 and 2, and the corresponding F and p values from the hypothesis testing. A value of p less than 0.05 indicates that the difference considered is significant, while a value of less than 0.01 corresponds to a highly significant difference. Values of p greater than 0.10 are marked with ‘ - ’ , as they would be indicative of differences far short of being statistically significant. It can be seen from the table that, in general, changes in speed variance were not statistically significant to the 0.05 level. However, at sites 2 and 3, the speed control techniques studied did produce reductions in speed variance that were significant to the 0.10 level as traffic approached the work zone. An inspection of the data reveals that each treatment condition produced a more negative change in speed variance for the entire traffic stream as it approached the work zone than did its control condition counterpart. Because reducing speed variance improves traffic safety, this observation indicates that the unmanned radar techniques applied in this study did have a beneficial impact on safety, as a more desirable change in speed variance of traffic approaching the work zone occurred when speed control techniques were applied.

4.2.3 Changes in Percent of Traffic Exceeding Threshold Speeds

In addition to attempting to reduce mean speed and speed variance, speed control techniques should also produce reductions in the percentage of traffic exceeding the speed limit. The percentage of traffic exceeding 65 mph and 55 mph at each station and the change between them are shown in Table 4.6. Cars and trucks will not be examined separately, as the sample sizes would be too small for comparing proportions. Hypothesis testing can be performed on the data (percent exceeding the speed limit at each station and the change between stations) to determine if such reductions in proportion are statistically significant. The null hypothesis is that the percentage of traffic exceeding the speed limit at station 1 and station 2, for a particular speed control condition, is equal (23). The calculation of the z-statistic for comparing proportions is performed as follows:

$$z = (P_1 - P_2) / \{ [P_1 (1 - P_1) + P_2 (1 - P_2)] / n \} \text{ where} \qquad (5)$$

P_1 = *portion of traffic exceeding speed limit at station 1*

P_2 = *portion of traffic exceeding speed limit at station 2*

n = *sample size*

The resulting *z* value, for a given comparison, is checked against a standard normal probability table to determine the corresponding value of *p* and the corresponding level of significance of the change in proportion. The results of the hypothesis testing are presented in Table 4.7, which lists the change in percentage exceeding 65 mph and 55 mph between observation stations 1 and 2, and the corresponding *z* and *p* values from the hypothesis testing. A value of *p* less than 0.05 indicates that the difference considered (change in percent of traffic exceeding 65 mph or 55 mph) is significant, while a value of less than 0.01 corresponds to a highly significant difference. Values of *p* greater than 0.10 are marked with ‘ - ’ , as they would be indicative of differences far short of being statistically significant. It can be seen from the table that at sites 1B and 3, highly significant ($p<0.01$) reductions in percent of traffic exceeding the speed limit occurred, as traffic entered the work zone, when the drone radar was active. At site 1A, the reduction fell just short of being statistically significant ($p=0.08$). At site 2, significant reductions were observed with no speed control technique, with drone radar, and with police presence. Study C at site 2 cannot be considered for analysis in percent of traffic exceeding the speed limit. This is due to the fact that the speed limit dropped from 65 mph to 55 mph at station 2, thus drivers may have been reducing their speeds between observation stations in response to the speed limit change rather than speed control conditions. It is interesting to note that at site 2 (studies A and B), the speed control techniques (drone radar and police presence) created highly significant reductions in the percent of traffic exceeding 65 mph as the traffic stream entered the work zone. A significant reduction did not occur when the speed control techniques were not applied. This attests well to the techniques' impact on the most flagrant speeders (specifically those exceeding the speed limit by more than 10 mph), a key target sector of the traffic stream.

4.2.4 Changes in Eighty-fifth Percentile Speeds

The top fifteen percent of the population, while representing the fastest drivers, also has significance in traffic engineering. Based on past research that concluded that radar detector use is most prevalent among high-speeding vehicles, a driver in this sector of the population has a higher probability of using a radar detector. Therefore, it is likely that a higher percentage of drivers in the top fifteen percent use radar detectors than does the traffic stream as a whole. In addition, the eighty-fifth percentile speed has long been used as a general rule for establishing an appropriate speed limit. The drivers exceeding this speed, under a normal distribution, are more than one standard deviation away from the mean speed. For many reasons, the eighty-fifth percentile speed has been of interest when considering the characteristics of a traffic stream.

The eighty-fifth percentile speeds for each condition studied at each observation station are listed in Table 4.8. It can be seen from the table for sites 1A, 1B, and 3, that the changes in eighty-fifth percentile speed as traffic entered the work zone were +0.2 mph, -0.9 mph, and -0.6 mph, respectively. With drone radar in operation, the respective changes were -0.9 mph, -3.4 mph, and -4.5 mph. Therefore, drone radar created reductions in the eighty-fifth percentile speed of approximately 1 mph to 5 mph, while with no speed control, the changes were less than 1 mph. At site 2, where the expectation of speed limit enforcement was high, the eighty-fifth percentile speed dropped 2 mph with no speed control technique. Interestingly, with drone radar and with police presence, reductions of 5.0 mph and 4.7 mph occurred. This testifies to the fact that the fastest drivers are also those most likely to use radar detectors.

The determination of whether statistically significant changes in eighty-fifth percentile speed occur is considerably more complex than for the other measures of effectiveness (MOE) considered. The parametric hypothesis testing performed on the other MOEs was based on parameters that define a normal distribution (mean and standard deviation). As the eighty-fifth percentile speed is not a defining parameter, parametric tests cannot be applied. Non-parametric tests, for which more assumptions about the distribution are made, the statistical theory is not as generally accepted, and the testing procedure is much more complex, would have to be used. A lesser degree of statistical validity would cloud the results. Additionally, the sample size for this sector of the population, given a typical data set of 100, would be fifteen vehicles, which is too small to confidently perform statistical testing and draw valid conclusions on the behavior of these drivers.