EFFECTS OF POLICE PRESENCE ON SPEED IN A HIGHWAY WORK ZONE:
Circulating Marked Police Car Experiment

By
Rahim F. Benekohal
Paulo T. V. Resende
Robin L. Orloski

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Investigation of speed control methods in work zones

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This study evaluated the effects of police presence on the speed of vehicles in a work zone and determined the "halo" effects of police presence (lasting effects when police are gone) on vehicular speeds. A marked police car circulated in a 4-mile long interstate highway work zone and actively enforced the speed limit laws. Variables such as the average speed, speed distribution, percentage of fast-moving motorists, and net speed reductions for cars and trucks were used for evaluation. The results indicated that the average speeds of the cars and trucks were 4.3-4.4, and 4.3-5.0 mph, respectively, lower when police were patrolling the work zone compared to no-police patrol condition. The percentage of fast-moving cars and trucks before the work space decreased by 14% and 32%, respectively, when police were in the work zone. These speed reductions indicate that the police presence was effective in decreasing the speed of vehicles in the work zone. The police presence had halo effects on trucks but not on cars. Trucks traveled at reduced speed when police were present in the work zone and this trend of traveling at the reduced speed continued for a time period at least one hour after the police departed from the work zone. However, cars traveled 2.4-3.0 mph faster and the percentage of fast-moving cars in the work zone increased after the police left the area.
ACKNOWLEDGMENT AND DISCLAIMER

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The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
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INTRODUCTION

The average speed of free flow traffic in construction zones often exceeds the posted speed limit. Speeding motorists slow down when they encounter a police car patrolling the area or when they perceive that the threat of getting a speeding ticket exists. This study examines the effects of police presence in a construction work zone on speed of vehicles and determines the "halo" effects (lasting effects when police are gone) of police presence on vehicular speed. The Illinois Department of Transportation (IDOT) had hired an off-duty police officer to patrol the work zone. The officer stayed in his car and actively enforced the speed limit laws.

The study is divided into two major parts:

1. The first part evaluates the effects of police presence on the average speed, speed distribution, percentage of fast moving motorists, and speed reductions that it may cause on cars and trucks.
2. The second part determines the halo effects of police presence on the travel speeds of cars and trucks inside the work zone.

Data for part "a" were collected with police in the work zone (treatment data) and without police (control data). The control data were collected on the day that no police officer was in the work zone and drivers faced the usual traffic control devices used in lane closures on highways. The treatment data were collected on another day when a circulating marked police car patrolled the work zone and issued tickets to speeding motorists. During the treatment day, speeds were affected by the presence of a circulating police patrol inside the work zone. Police remained in the area for 4 hours from 11 am till 3 pm. Data for part "b" were collected immediately after police left the area.

Police presence in a work zone is an effective way of slowing down the speeding motorists, but it becomes very expensive to have a law enforcement officer in every work zone. A police officer stationed at one point would significantly increase the speed limit compliance at that location; however, the effects would be limited to a smaller area. On the other hand, a circulating police car would impact a larger area, but it may have less overall speed reduction effects. Some drivers with citizens band (CB) radios communicate police presence in the work zone and select their speeds accordingly.

Previous Studies

The effects of police presence in a construction zone on traffic speed vary with the function assigned to the law enforcement officer. Graham et al. (1) reported on the effects of law enforcement on speed and erratic maneuvers on a two-lane (per
rural freeway reduced to a two-lane two-way operation by means of a crossover section. The erratic maneuvers were defined as a single vehicle suddenly swerving or braking on approaching a transition area. The law enforcement by a highway patrolman car stationed on the roadside not only reduced the erratic maneuver rate, but also reduced the mean vehicle speed by 2.77 mph (1).

Richards et al. (2, 3) investigated the immediate effects (1-2 hours) of the following law enforcement treatments on speed reduction: stationary patrol car, police traffic controller, circulating patrol car, stationary patrol car with lights on, and stationary patrol car with radar on. The immediate effects (1-2 hours) of the law enforcement treatments on speed were a reduction of 2-3 mph for a circulating patrol car, 9-13 mph for a police traffic controller, and 3-12 mph for a stationary police car. The immediate speed reduction effects of the stationary police car treatment were consistently less than the innovative flagging treatment (2,3). Richards et al. (2, 3) reported that the most effective law enforcement treatment was a uniformed police officer standing on the roadside and controlling traffic and the least effective treatment was the circulating patrol car. A uniformed police officer directing traffic must always be alert and therefore must be relieved every few hours, resulting in a need for additional trained officers. Therefore, law enforcement officers may not be readily available or willing to direct work zone traffic.

Noel et al. (4, 5) evaluated the long-term (two weeks) and short-term (within three days) effectiveness of law enforcement on speed reduction on a six-lane freeway construction zone. The treatments were a marked police car with cruiser light and radar on and a uniformed police officer controlling traffic. The long-term and short-term effects of the police traffic controller treatment on multi-lane freeways led to speed reductions in the range of 2.3-6.8 mph, using data for all vehicles (4, 5). The results from the police radar treatment were not as consistent as those from the police traffic controller. The speed change ranged from +3.6 mph to -8.4 mph. Police radar and police controllers were found to be effective in both long-term and short-term experiments. Police controllers reduced speeds by 6.3 mph over a short-term period and 6.8 mph over a long-term period, when one out of three lanes was open to traffic (4, 5). Police radar treatments were effective in reducing speeds by 5.4 mph during a long-term period, when one lane was open to traffic (4, 5).
STUDY APPROACH

The approach used in this study is commonly known as the before and after study with control group. The data collection and data analysis steps are performed according to this method. The following sections describe these steps in more detail.

Study Site

Data were collected in a work zone in the southbound direction of I-57, near Mattoon, in Coles County, Illinois. The construction zone had an approximate length of 3.5 miles. The highway has two lanes per direction, but one lane was closed in each direction during the construction period. The construction site mainly consisted of bridge deck reconstruction and some shoulder and ramp improvements. There were approximately 5 to 10 workers behind safety shaped (jersey) construction barriers. The construction crew was equipped with a large crane and some small tractor-type equipment. The weather conditions were hot and sunny with no rain during the two-day data collection period.

The construction zone traffic control plan was one of IDOT’s standard plans for lane closures on multi-lane highways. The standards were prepared based on the requirements of the Manual on Uniform Traffic Control Devices (MUTCD) (6). Figure 1 shows the layout of the work zone and the traffic control devices used at the site.

The speed limits outside of the work zone were 65 mph for cars and 55 mph for trucks. However, a regulatory 45 mph speed limit was in effect inside the construction zone for all vehicles when flashing beacons on the speed limit signs were turned on. The flashing beacons were turned on in the morning when the crew started working, and were turned off at 4 pm and 5 pm on the days that the control data and the treatment data were collected, respectively.

Data Collection

Data were collected for control and treatment conditions at three speed stations. Figure 1 shows the location of the speed stations. The first station, Station 1, was located outside the traffic control zone where two lanes were open to traffic. The second and third stations, Stations 2 and 3, were located inside the work zone where only one lane was open to traffic. Data were collected using mechanical traffic counters and road tubes.

Treatment data were collected from 10 am to 6 pm on June 5th, 1990. A police officer was present in the work zone from 11 am to 3 pm. At 3 pm, police left the site and there was no indication of other police officers in the work zone. While the treatment data were being collected, the marked police vehicle circulated within
Figure 1. Work zone signs on SB I-57 during Police Presence Study

Station 1

2 miles

Station 2

3400 ft

Station 3

1000 ft

1 mile

road construction next 8 miles

give 'em a brake slow down

right lane closed 1/2 mile

right lane closed ahead

45 mph

shoulder drop off

workers ahead

speed limit 45 when flashing

dewitt rd

rt 16 bridge

bridge at mp 187

→→ indicates arrow board
the work zone and patrolled both the northbound and southbound
directions of the highway. On the treatment day, the speed limit
was actively enforced and the police officer issued 12 speeding
tickets. Control data were collected from 10 am to 6 pm on June
4th, 1990. There were no police present in the work zone from 11
am to 6 pm, but police were in the work zone until 11 am on June
4th. Similar construction activities were going on when control
and treatment data were collected. The flashing lights on the
speed limit signs were on during data collection.

In addition to the speed data, the conversation among drivers,
police radar usage in the work zone, and traffic flow conditions
at the speed stations were also monitored. Two CB radios were used
to monitor the conversations among drivers. A radar detector was
used to monitor how often the police officer was using radar.
Furthermore, Stations 2 and 3, as well as the activities over the
Route 16 bridge, were monitored to record any unusual behavior that
might disturb the normal flow of traffic near the stations.

Data Reduction

The raw traffic data collected by the Traffic Counter and
Classifiers (TCC) were stored in the internal memory of the unit.
Each TCC has 64 K of memory, which can store individual records of
up to 8,000 vehicles. The data were downloaded to an IBM PC and
were stored in ASCII format. In order to reduce the raw data to
useful information, a Fortran program called TRAFFIC was written to
perform sorting, classification, and error checking on the raw
data. The TRAFFIC program deletes any duplicated entries from the
file, separates the data according to lane traveled, computes the
headway of successive vehicles in each lane, filters out erroneous
data, and separates free flow traffic data from that of platooning
vehicles.

Flows in Traffic Stream

The vehicles in a traffic stream were classified into free flow
and platooning. A vehicle was considered to be in free flow
traffic when its time headway was greater than 5 seconds, otherwise
it was considered to be a member of a platoon. A vehicle in the
free flow traffic could travel at its desired speed because it was
not blocked by the vehicle in front of it. However, a platooned
vehicle had to follow the leader of the platoon; thus, its speed
was influenced by the speed of the lead car. The sum of free flow
and platooning vehicles comprised the total flow traffic.

Speeds of free flow and total flow traffic were compared to
assess the difference between the two. This difference is
important because police presence affects speed of all vehicles,
but only the free flow traffic is used to assess the police
presence. A platooning vehicle is blocked by the leader of the
platoon and often has to travel below its desired speed. It is
possible that a platooning vehicle may voluntarily reduce its speed
due to the police presence and still remain in the platoon. Although the speed reduction on a platooning vehicle may not be
voluntary, it does contribute to the overall speed reduction and
therefore may increase traffic safety.

The platooning traffic should not be used for police presence
evaluation because, for a platooning vehicle, it is very difficult
to separate the voluntary speed reduction from the one imposed by
the leader of the platoon. In this study only the free flow
traffic data are used for statistical analyses. The relationships
between the free flow and the total flow traffic are discussed in
the following section.

Comparison of Free Flow and Total Flow Speeds

The vehicles in a traffic flow were grouped into free flow and
platooning categories. A vehicle was considered to be in free flow
traffic when its time headway was greater than 5 seconds;
otherwise, it was considered to be in a platoon. A vehicle in
free flow traffic could travel at its desired speed because it was
not blocked by the vehicle directly in front of it. However, a
platooning vehicle had to follow the leader of the platoon, and its
speed was influenced by the speed of the lead vehicle.

It is possible that the platooning vehicle could voluntarily
reduce its speed due to the police presence and still remain in the
platoon. However, in general, a platooning vehicle often had to
travel below its desired speed. The sum of free flowing and
platooning vehicles constitutes the total flow traffic.

The free flow and total flow speeds were compared to assess the
difference between the two (Figures 2 through 5). The average
speeds were computed using the hourly traffic volumes. As
demonstrated in Figures 2 through 5, the average speed of vehicles
in free flow did not differ substantially from those of vehicles
platooning. In general, the average free flow speeds were slightly
higher than the total flow speeds. This observation is true for
both control and treatment data.

Occasionally, the average free flow speeds were lower than the
total flow speeds. This occurred when a group of fast moving
vehicles were platooned. Also, when a greater difference between
free flow and total flow vehicles was observed, as in Figure 2 for
Station 3, that fact may be explained by the presence of some
platooning vehicles with relatively low speeds, which does not
imply any other effect on the overall speed trend.

The analysis of the curves indicated that either the average
free flow speed or the total flow speed could be used for the
traffic conditions in this site. However, the average speed of
platooning vehicles should not be used for police presence
evaluation because, for a platooning vehicle, it is very difficult
to separate the speed reduction effects of police presence from the
one imposed by the leader of the platoon.
Figure 2. Free and total flow speeds of cars at 3 Stations - Control Data

Average Speed (mph)

75
70
65
60
55
50

10-11 11-12 12-01 01-02 02-03 03-04

Hourly Period

Station 1
Station 3
Station 2

free flow dashed and total flow solid

Figure 3. Free and total flow speeds of trucks at 3 Stations - Control Data

Average Speed (mph)

70
65
60
55
50

10-11 11-12 12-01 01-02 02-03 03-04

Hourly Period

Station 1
Station 3
Station 2

free flow dashed and total flow solid
Figure 4. Free and total flow speeds of cars at 3 Stations - Treatment Data

Figure 5. Free and total flow speeds of trucks at 3 Stations - Treatment Data
Time Periods for Data Analysis

During the data collection, it was observed that the speed of vehicles during certain time periods may have been influenced by factors other than police presence (external factors). The effects of the external factors have to be removed from the effects of the police, or else the time periods should not be used for evaluation of police presence. Otherwise, a misleading conclusion may be drawn. The external factors are described below:

(1) A flagman was present near Station 2 from 2 to 3 pm on the day the control data were collected.
(2) The flashing lights on the speed limit signs were turned off at different times in the two days of data collection.
(3) Police remained at Station 2 from 12 noon to 1 pm on the day the treatment data were collected.

The data for evaluation of the police presence and police lasting effects were selected such that the influence of the external factors were eliminated. The effects of the external factors on speed are discussed in Appendix B. It was decided to use the data from 1 pm to 2 pm for statistical analysis of the police presence effects. For the evaluation of the halo effects of police presence, the data from 3 pm to 4 pm will be used. These time periods have provided enough data to perform the necessary statistical analyses.

Highlights of Traffic and CB Monitoring

On the control day (June 4th), police were in the work zone until 11 am, but not thereafter. Around 2:08 pm a small crew and a flagger with a STOP/SLOW paddle started working on the southbound shoulder lane of the diverging ramp before Station 2. Although the flagger's purpose was to slow down traffic on the ramp, his presence close to the highway may have influenced some drivers on the freeway. At 2:42 the flagger and the crew had clearly moved onto the ramp. The flashing lights on the speed limit signs were turned off at 4:00 pm.

On the treatment day (June 5th), police arrived at the work zone at 11:00 am and left at 3:00 pm. The policeman used his radar in "instant" mode (transmitting signals only when needed to measure speed of a vehicle). At 12:04 the policeman pulled someone over right before Station 2 and remained there for about 10 minutes. Drivers with CB radios talked about police and announced the mile post he was at and the direction he was facing. On the average, about a dozen times in an hour the police location was reported on the CB radios. During the four-hour period, he wrote about 12 speeding tickets. At 5:09 the flashing beacons on the speed limit signs were turned off.
Data Analysis Approach

All statistical analyses were performed using a Personal Computer version of the Statistical Analysis System (SAS) software, PC-SAS Version 6.04, (7). A separate statistical analysis was performed for cars and trucks due to the difference in the posted speed limits and the differences found in their respective speed distributions. The Student’s t-test and the F-test were used for statistical analysis. These tests are briefly discussed below.

Comparing Speed Distributions

The F-test was used to compare speed variances of two data sets in order to determine whether or not they had equal variances (whether on not distributions had a similar shape). Equal variances implied that the shape of the distributions were the same. The F-test was performed with a 95% confidence level. The calculated F-value was computed as:

\[
F = \frac{S_1^2}{S_2^2}
\]

where:
- \( S_1^2 \) = Variance of speeds for data set 1.
- \( S_2^2 \) = Variance of speeds for data set 2.

The results of the F-test also determined the type of t-test to be used for comparing average speeds. When the distributions of speeds were not the same (unequal variances), an approximate value of ‘t’ was used to reflect the difference in the shape of the distributions (7).

Comparing Mean Speeds

The t-test was used to compare the average speed of one data set to the average speed of another data set. The t-value was computed as:

\[
\frac{U_1 - U_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2} \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}}
\]
where:

\[ \bar{U}_1, \bar{U}_2 = \text{Average speeds for data sets 1 and 2.} \]
\[ n_1, n_2 = \text{Number of observations in data sets 1 and 2.} \]

One assumption of the t-test was that the speed data had a normal distribution. The data used in this study were for free flow vehicles and, therefore, did not necessarily have a normal distribution. However, the t-test was still viable because of its relative insensitivity to normal distributions (8). Although calculated and approximate t-values for the test were nearly identical, the approximated values were used whenever the distributions had unequal variances.

Analyzing Net Speed Reductions

In order to find out whether there was an additional speed reduction due to the presence of circulating police in the construction zone, the net speed reductions were computed. The net speed reduction at Station 2 was computed using the data from Station 1 as the control station. In other words, the speed difference between the treatment and control data at Station 1 was used as the expected value for the speed difference at Station 2, if police were not in place. A t-test with 95% confidence level was used to determine if the net reduction was statistically significant. The t-test was made by determining the net speed reduction from the following equation:

\[ \text{Net Speed Change at Station } n = (\bar{U}_{nt} - \bar{U}_{nc}) - (\bar{U}_{1t} - \bar{U}_{1c}) \]

Where:

\[ \bar{U}_{1t} = \text{The treatment mean speed at Station 1.} \]
\[ \bar{U}_{nt} = \text{The treatment mean speed at Station } n, \ n=2 \text{ or } 3. \]
\[ \bar{U}_{1c} = \text{The mean speed for control data at Station 1.} \]
\[ \bar{U}_{nc} = \text{The mean speed for control data at Station } n, \ n=2 \text{ or } 3. \]
ANALYSIS OF POLICE PRESENCE EFFECTS

This section will describe the speed characteristics of vehicles traveling through the work zone during the control condition (no police) and when a marked police vehicle circulated in the work zone and actively enforced the speed limit laws. Variables such as percentage of vehicles exceeding a speed level, net speed reductions from station to station, and general speed trends will be discussed for control and treatment data. The speed characteristics of vehicles during the control period depict the prevalent performance of drivers traveling through work zones. However, drivers may travel at lower speeds when facing the presence of police within the work zone. The difference between with-police and without-police conditions would indicate the effectiveness of police presence in the work zone.

Description of Circulating Police Experiment

A marked police car patrolled both the north and southbound directions of the freeway. The circulating police patrol was inside the work zone from 11 am to 3 pm, and wrote 12 tickets. After 3 pm the police officer left the work zone and there were no other police in the study area, but data collection continued until 6 pm. The data collected between 3 and 4 pm will be used in the analysis of lasting police effect within the work zone (halo effect).

Speed Characteristics

In the following sections, the speed characteristics for cars and trucks during the control and the treatment periods are discussed. A summary of speed statistics was given in Tables 1 and 2. Outside the work zone (Station 1) vehicles traveled at almost the same speeds and showed similar speed distributions with and without police presence in the work zone. However, inside the work activity area (Stations 2 and 3), the speeds were lower compared to control data, when police were in the work zone. These comparisons are summarized in Table 3.

Speed frequency distributions for the control and treatment conditions are shown in Figures 6 through 9. The Figures clearly show the shift from the higher speeds at Station 1 to the lower speeds at Station 2 and back to the higher speeds at Station 3. The average speeds were lower at Station 2 than Station 1, but higher at Station 3 than Station 2. The same trend was observed for passenger cars and trucks at other speed levels (see Figure 10 through 13 which show the percentages of vehicles exceeding a given speed level).
### TABLE 1

SPEED STATISTICS FOR CONTROL DATA - CARS AND TRUCKS

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Cars</th>
<th></th>
<th>Trucks</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Station</td>
<td>Mean Speed</td>
<td>69.22</td>
<td>55.00</td>
<td>66.27</td>
<td>63.21</td>
<td>51.56</td>
</tr>
<tr>
<td></td>
<td>Min. Speed</td>
<td>53.0</td>
<td>37.0</td>
<td>48.0</td>
<td>55.0</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>Max. Speed</td>
<td>85.0</td>
<td>77.0</td>
<td>86.0</td>
<td>76.0</td>
<td>62.0</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>4.89</td>
<td>7.01</td>
<td>8.06</td>
<td>4.52</td>
<td>5.23</td>
</tr>
<tr>
<td></td>
<td>No. of Obs.</td>
<td>171</td>
<td>126</td>
<td>74</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Percent Exceeding Speed Limit</td>
<td>75.4</td>
<td>91.3</td>
<td>100.0</td>
<td>95.7</td>
<td>87.8</td>
</tr>
</tbody>
</table>

### TABLE 2

SPEED STATISTICS FOR TREATMENT DATA - CARS AND TRUCKS

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<th>Vehicle</th>
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<th>Trucks</th>
<th></th>
<th></th>
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</thead>
<tbody>
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<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Station</td>
<td>Mean Speed</td>
<td>68.01</td>
<td>49.44</td>
<td>60.56</td>
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<td></td>
<td>Min. Speed</td>
<td>48.0</td>
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<td>46.0</td>
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<td>34.0</td>
</tr>
<tr>
<td></td>
<td>Max. Speed</td>
<td>81.0</td>
<td>65.0</td>
<td>84.0</td>
<td>70.0</td>
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<td></td>
<td>Standard Deviation</td>
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<td>6.09</td>
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<td>5.06</td>
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<td>69</td>
<td>62</td>
<td>57</td>
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<td></td>
<td>Percent Exceeding Speed Limit</td>
<td>72.9</td>
<td>76.8</td>
<td>100.0</td>
<td>91.9</td>
<td>56.1</td>
</tr>
<tr>
<td>CONDITION</td>
<td>MEAN</td>
<td>VARIANCE</td>
<td>Alpha for &quot;F&quot; TEST</td>
<td>Alpha for &quot;t&quot; TEST</td>
<td>Interpretation with 95% confidence</td>
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<tr>
<td><strong>CARS</strong></td>
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<td></td>
</tr>
<tr>
<td>STATION 1</td>
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<td>0.07</td>
<td>0.0464</td>
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<td>32.070</td>
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<td>STATION 2</td>
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<tr>
<td>CONTROL</td>
<td>55.007</td>
<td>49.252</td>
<td>0.15</td>
<td>0.000</td>
<td>Equal variances and Different Means</td>
<td></td>
</tr>
<tr>
<td>POLICE</td>
<td>49.442</td>
<td>37.198</td>
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</tr>
<tr>
<td>STATION 3</td>
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<td>CONTROL</td>
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<td>64.964</td>
<td>0.46</td>
<td>0.000</td>
<td>Equal variances and Different Means</td>
<td></td>
</tr>
<tr>
<td>POLICE</td>
<td>60.565</td>
<td>54.479</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRUCKS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATION 1</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CONTROL</td>
<td>63.212</td>
<td>20.512</td>
<td>0.50</td>
<td>0.1655</td>
<td>Equal variances and equal means</td>
<td></td>
</tr>
<tr>
<td>POLICE</td>
<td>62.048</td>
<td>17.123</td>
<td></td>
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</tr>
<tr>
<td>STATION 2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CONTROL</td>
<td>51.560</td>
<td>27.395</td>
<td>0.80</td>
<td>0.0000</td>
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<td></td>
</tr>
<tr>
<td>POLICE</td>
<td>45.298</td>
<td>25.634</td>
<td></td>
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</tr>
<tr>
<td>STATION 3</td>
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<tr>
<td>CONTROL</td>
<td>62.944</td>
<td>70.678</td>
<td>0.11</td>
<td>0.0016</td>
<td>Equal variances and Different Means</td>
<td></td>
</tr>
<tr>
<td>POLICE</td>
<td>57.477</td>
<td>42.576</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6. Speed frequencies of cars in Control Period

Figure 7. Speed frequencies of trucks in Control Period
Figure 8. Speed frequencies of cars in Treatment Period - (1-2 pm)

Figure 9. Speed frequencies of trucks in Treatment Period - (1-2 pm)
Figure 10. Percent of cars exceeding a given speed during the Control Period

Figure 11. Percent of trucks exceeding a given speed during the Control Period
Figure 12. Percent of cars exceeding a given speed - Treatment Data (1-2 pm)

Figure 13. Percent of trucks exceeding given speed - Treatment Data (1-2 pm)
Cars in Control Condition

Cars reduced their speeds at Station 2 compared to Station 1, but increased to higher speeds when reaching Station 3. This speed trend can be clearly seen in Figure 14. Cars traveled at speeds ranging from 53 to 85 mph outside the work zone and from 37 to 86 mph inside the construction zone. On the average, passenger cars exceeded the posted speed limit by 4.2, 10.0, and 21.2 mph at Stations 1, 2, and 3, respectively.

Nearly 75% of cars were traveling at speeds higher than the 65 mph speed limit at Station 1. Nevertheless, at Station 2 and Station 3, the percentages of cars speeding over the 45 mph speed limit were even higher than at Station 1, as represented by 91% and 100.0%, respectively. The percentages of cars traveling 10 mph over the speed limit were approximately 10%, 45%, and 92% at Stations 1, 2, and 3, respectively. The percentages of cars exceeding a given speed are presented in Figure 10.

Trucks in Control Condition

Similar to passenger cars, trucks also reduced their speeds at Station 2 compared to Station 1, but increased them by the time they reached Station 3. The average speed change for trucks is presented in Figure 15. During the control period, truck drivers traveled at a range of 55 to 76 mph outside the work zone and a range of 41 to 88 mph inside the work zone. The average speeds of trucks were approximately 8.2, 6.5, and 17.9 mph higher than the speed limit at Stations 1, 2, and 3, respectively.

The percentage of trucks exceeding the posted speed limit of 55 mph at Station 1 was 96%. At Station 2 and Station 3, the percentages of trucks traveling above the 45 mph speed limit were 88% and 100%, respectively. The percentages of trucks traveling 10 mph above the speed limit were approximately 23%, 22%, and 78% at Stations 1, 2, and 3, respectively. The percentage of trucks exceeding a given speed level is presented in Figure 11.

Cars in Police Presence Condition

When the police were in the work zone (treatment period), passenger cars presented a range of speeds varying from 48 to 81 mph outside of the work zone, and from 28 to 84 mph inside the construction zone. As shown in Figure 14, cars traveled at average speeds approximately 3.0, 4.4, 15.5 mph higher than the posted speed limits at Stations 1, 2, and 3, respectively. Station 3 showed the highest difference between the average speed and the posted speed limit (approximately 15.5 mph). Station 3 also presented the widest speed range of 38 mph and the highest standard deviation of 7.38 mph.

Speeding cars accounted for nearly 73%, 77%, and 100% of all
Figure 14. Average speeds (mph)
for Cars - Control versus Treatment

Figure 15. Average speeds (mph)
for Trucks - Control versus Treatment
passenger cars crossing Stations 1, 2, and 3, respectively. The percentages of cars traveling at least 10 mph above the speed limit were approximately 7%, 17%, and 74% at Stations 1, 2, and 3, respectively. The percentage of cars exceeding a given speed is shown in Figure 12. It is important to note that there was a reduction of approximately 15% in the percentage of passenger cars traveling above the speed limit at Station 2, when police were present in the work zone. The percentage of cars traveling higher than 10 mph above the speed limit was even higher at Station 3 than at Station 1, despite the fact that Station 3 was an inside work zone station.

**Trucks in Police Presence Condition**

When police were in the work zone, trucks presented average speeds lower than those displayed during the control condition. On the average, trucks traveled approximately 7.0, 0.3, and 12.5 mph higher than the posted speed limits for Stations 1, 2, and 3, respectively (see Figure 15). Trucks had the highest speed range (27 mph) and the highest standard deviation of 6.52 mph at Station 3.

The percentages of trucks exceeding the speed limits were approximately 92%, 56%, and 100% at Stations 1, 2, and 3, respectively. The percentage of trucks with 65 mph speed or higher was about 18% at Station 1. At Stations 2 and 3, the percentages of trucks traveling faster than 55 mph were 4% and 52%, respectively.

**Net Speed Reductions**

The net speed reductions for passenger cars and trucks at Station 2 and Station 3 were determined according to the procedures presented in the Data Analysis Approach section. The net speed reductions for passenger cars and trucks are summarized in Table 4.

**Net Speed Reduction for Cars**

The net speed reductions for passenger cars were 4.3 mph at Station 2 and 4.4 mph at Station 3. The results of t-tests showed that the net reductions were significant, implying that there were decreases in average speeds due to the presence of police. These results indicated that the average speeds of the cars inside the work zone were 4.3-4.4 mph lower when police were patrolling the work zone compared to the no-police condition (Figure 16).
### Table 4

**NET SPEED REDUCTIONS (MPH) FOR CIRCULATING POLICE**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Sta. 1 and Sta. 2</th>
<th>Between Sta. 1 and Sta. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Speed Reduction</td>
<td>t-Test Inference</td>
</tr>
<tr>
<td>Cars</td>
<td>4.3</td>
<td>Significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>5.0</td>
<td>Significant</td>
</tr>
</tbody>
</table>

**Net Speed Reduction for Trucks**

Similarly, trucks presented significant net speed reductions when police were present in the work zone. Trucks displayed an average net speed reduction of 5.0 mph at Station 2, and 4.3 mph at...
Station 3. These reductions were statistically significant. Thus, on the average, trucks traveled 4.3-5.0 mph slower when the police were in the work zone. These net speed reductions demonstrate the effectiveness of the police presence in decreasing truck speeds inside the construction zone (Figure 16).
LASTING EFFECTS OF POLICE PRESENCE

The effect of police presence in the construction zone may last beyond the actual time the police are present in the work zone. Traffic moves at a reduced speed when police are present in the work zone and this trend of traveling at the reduced speed may continue for a time period immediately after the police departure from the work zone. Furthermore, drivers with a citizen band (CB) radio may communicate with other drivers regarding police presence in the work zones.

Some drivers may still take the "threat" of police presence seriously and may travel at reduced speeds after police leave the work zone. Thus, the police presence may have halo effects on vehicle speeds. If the halo effect is sustained, one police officer may control a few adjacent work zones without a significant loss in his/her effectiveness on speed reduction. This section will examine the lasting effect of police presence.

Data for Lasting Police Experiment

Data used to evaluate the lasting effects were collected from 3 pm to 4 pm on the day police were in the work zone. This data were compared to the data for 1-2 pm when police were in the work zone. The police left the area at 3 pm. As mentioned before, the analysis of the speed characteristics of vehicles passing the work zone during a period where police were present and a period right after police left, may determine the lasting police effects upon those vehicles. For this analysis, the time period from 1 pm to 2 pm is used as "comparison group" (police in), and the time period from 3 pm to 4 pm is characterized as lasting effect experiment data (police out). Vehicles, particularly cars, presented relatively higher speeds at Stations 2 and 3 after police left the construction zone. Trucks have presented smaller differences between the two periods than passenger cars. The speed characteristics will be discussed in the following section.

Speed Characteristics

In this section, the speed characteristics for cars and trucks during the time period from 3 pm to 4 pm are discussed. A summary of speed statistics was given in Table 5. However, in the work activity area (Stations 2 and 3) the speeds of cars were higher after the police departure, while those of trucks were not (see Table 6). The speed frequencies for cars and trucks are presented in Figures 17 and 18. As the figures show, the speeds are shifted toward lower values at Station 2, but are substantially increased at Station 3. The percentages of vehicles exceeding a given speed
at the three Stations also supports this observation (see Figures 19 and 20). Cars and trucks, on the average, reduced their speeds at Station 2, but increased them by the time they reached Station 3. The average speeds at Station 3 were only a few mph below the speeds at Station 1. The same trend was observed for both passenger cars and trucks. Figures 21 and 22 show the average speed of passenger cars and trucks for time periods of 1-2 pm and 3-4 pm at Stations 1, 2, and 3.

### TABLE 5

**SPEED STATISTICS FOR LASTING POLICE EXPERIMENT (PERIOD 3-4 PM)**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Cars</th>
<th>Trucks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Mean Speed</td>
<td>68.61</td>
<td>52.43</td>
<td>64.17</td>
</tr>
<tr>
<td>Min. Speed</td>
<td>54.0</td>
<td>42.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>91.0</td>
<td>72.0</td>
<td>81.0</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>5.63</td>
<td>5.65</td>
<td>7.08</td>
</tr>
<tr>
<td>No of Obs.</td>
<td>136</td>
<td>83</td>
<td>64</td>
</tr>
<tr>
<td>Percent Exceeding Speed Limit</td>
<td>69.9</td>
<td>92.8</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Cars in Lasting Police Experiment**

During the two time periods the average speeds and speed distributions of vehicles were similar at Station 1 (outside the work zone). During the 3-4 pm time period, the speed of passenger cars varied from 54 to 91 mph at Station 1, and from 42 to 81 mph at Stations 2 and 3. Cars traveled at average speeds approximately 3.6, 7.4, and 19.2 mph higher than the posted speed limits at Stations 1, 2, and 3, respectively. Station 3 presented the highest difference between the average speed and the posted speed limit and the highest standard deviation of 7.08 mph. However, Station 2 displayed the widest speed range of 37 mph. Speeding cars accounted for approximately 70%, 93%, and 100% of the passenger cars crossing Stations 1, 2, and 3, respectively. The percentages of cars going at least 10 mph above the speed limit were nearly 10%, 27%, and 86% at Stations 1, 2, and 3,
<table>
<thead>
<tr>
<th>CONDITION</th>
<th>MEAN</th>
<th>VARIANCE</th>
<th>Alpha for &quot;F&quot; TEST</th>
<th>Alpha for &quot;t&quot; TEST</th>
<th>Interpretation with 95% confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATION 1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>POLICE IN</td>
<td>68.015</td>
<td>32.070</td>
<td>0.94</td>
<td>0.3824</td>
<td>Equal variances and equal means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>68.617</td>
<td>31.708</td>
<td></td>
<td></td>
<td></td>
</tr>
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</tr>
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<td>POLICE IN</td>
<td>49.442</td>
<td>37.198</td>
<td>0.47</td>
<td>0.0009</td>
<td>Equal variances and Different Means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>52.433</td>
<td>31.923</td>
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<td></td>
<td></td>
</tr>
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<td>STATION 3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POLICE IN</td>
<td>60.565</td>
<td>54.479</td>
<td>0.74</td>
<td>0.0048</td>
<td>Equal variances and Different Means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>64.171</td>
<td>50.197</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRUCKS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATION 1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>POLICE IN</td>
<td>62.048</td>
<td>17.123</td>
<td>0.45</td>
<td>0.6108</td>
<td>Equal variances and equal means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>62.428</td>
<td>20.639</td>
<td></td>
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<tr>
<td>STATION 2</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>POLICE IN</td>
<td>45.298</td>
<td>25.635</td>
<td>0.12</td>
<td>0.3195</td>
<td>Equal variances and equal means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>46.111</td>
<td>17.422</td>
<td></td>
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<td>STATION 3</td>
<td></td>
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</tr>
<tr>
<td>POLICE IN</td>
<td>57.477</td>
<td>42.576</td>
<td>0.53</td>
<td>0.5523</td>
<td>Equal variances and equal means</td>
</tr>
<tr>
<td>POLICE OUT</td>
<td>58.203</td>
<td>35.964</td>
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</tbody>
</table>
Figure 17. Speed frequencies of cars in Lasting Police Experiment (3-4 pm)

Figure 18. Speed frequencies of trucks in Lasting Police Experiment (3-4 pm)
Figure 19. Percent of cars exceeding a given speed - Lasting Police Experiment

Figure 20. Percent of trucks exceeding a given speed - Lasting Police Experiment
Figure 21. Average speeds (mph) for cars - Lasting Police Experiment

Figure 22. Average speeds (mph) for trucks - Lasting Police Experiment
respectively. The percentage of cars exceeding a given speed is displayed in Figure 19.

**Trucks in Lasting Police Experiment**

Trucks presented a range of speed varying from 51 to 78 mph at Station 1, and from 39 to 74 mph at Stations 2 and 3. Trucks traveled approximately 7.0, 1.1, and 13.2 mph higher than the posted speed limits for Stations 1, 2, and 3, respectively. The percentages of trucks driving faster than the speed limit were approximately 96%, 51%, and 100% at Stations 1, 2, and 3, respectively. Compared to the percentages of 92%, 56%, and 100% at Stations 1, 2, and 3, respectively, presented during the control period, trucks seem to be influenced by the lasting effects of radar, mainly at Station 2. The percentages of trucks traveling at speeds at least 10 mph above the posted speed limits were approximately 22%, 2.8%, and 62% at Stations 1, 2, and 3, respectively. In general, trucks were more affected by the presence of police than cars and the effects lasted at least for one hour after police left the site. This increased effectiveness is mainly due to a higher degree of radar detector and CB usage among truck drivers.

**Net Speed Changes**

Net speed changes for cars and trucks at Stations 2 and 3 were computed using the procedure described in the Data Analysis Approach section. The speeds in the time period after the police left (3-4 pm) were compared to the speeds for a time period when police were in the work zone (1-2 pm). If the speeds after police left remained at the levels exhibited with police, this would indicate that the police effect was sustained. However, if the speeds increased after police left it would imply that police did not have a lasting effect. Table 7 summarizes the net speed changes for cars and trucks.

**Net Speed Changes of Cars in Lasting Police Experiment**

The net speed increase for passenger cars at Station 2 was approximately 2.4 mph which, according to the t-test, was considered to be a significant increase (Figure 23). The net speed increase for cars between Station 1 and Station 3 was 3 mph which was also considered to be significant. These results indicated that cars traveled faster in the work zone after the police left the area. This means that the speed reduction effects of police presence inside the construction zone did not influence the
TABLE 7

NET SPEED CHANGES (MPH) FOR LASTING POLICE EXPERIMENT

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>At Station 2</th>
<th>At Station 3</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Net Speed Change</td>
<td>t-Test Inference</td>
</tr>
<tr>
<td>Cars</td>
<td>2.4</td>
<td>Significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>0.4</td>
<td>Not Significant</td>
</tr>
</tbody>
</table>

behavior of passenger car drivers in a period right after the police left. This finding is supported by the fact that only a small fraction of car drivers use radar detectors and listen to CB radios. Pigman et al (9) estimated that only 11% of car drivers use radar detectors.

Figure 23. Net speed reductions (mph) of cars & trucks - Lasting Police Experiment
Speed Changes of Trucks in Lasting Police Experiment

Trucks did not present statistically significant net speed changes at Station 2 or 3. The net speed increase for trucks was approximately 0.4 mph between Station 1 and Station 2 (Figure 23). Between Station 1 and Station 3, the truck net speed increase was about 0.3 mph. These results demonstrate that the speed reduction effects of police did not diminish immediately after the police left the work zone. One of the reasons for that effect may be the high level of CB and radar detector usage among truck drivers. Pigman et al (9) reported that 42% of trucks use radar detectors. The speed reduction effects of police presence inside the work zone on trucks lasted for at least one hour immediately after the police left.
CONCLUSIONS

The statistical analysis of the data collected indicated that police presence (a circulating marked police car) in the highway work zone was effective in reducing the average speeds and percentages of fast moving cars and trucks. The average speeds of the cars inside the work zone were 4.3-4.4 mph lower when police were patrolling the work zone compared to the no-police condition. Similarly, trucks presented speed reductions of 4.3-5.0 mph due to police presence. The percentages of cars and trucks exceeding the speed limit decreased by 14% and 32%, respectively, at a location before the work space. However, after passing the work space, cars and trucks increased their speeds.

The analysis of the halo effects of police presence (lasting police effects) indicated significant lasting police effects on trucks, but not on cars. During a one-hour period immediately following the police departure, the average speed of cars increased by 2.4-3.0 mph, but for trucks the increase was only 0.3-0.4 mph. The results indicated that cars significantly increased their speeds in the work zone after police left the area, but trucks kept traveling at the reduced speed. Although cars increased their speeds after police left the work zone, their speeds were still lower than those for the control data which were collected on a day when police were not in the work zone. These results indicated that the speed reduction effects of police on trucks did not diminish right after the police left the work zone, but tapered off for cars. For trucks, the speed reduction effects of police presence inside the work zone lasted for at least one hour immediately after the police left.

RECOMMENDATIONS

The presence of a circulating police car inside the work zone was effective in reducing the speed of cars and trucks. The speed was reduced not only near the police car, but also throughout the work activity area. It is recommended to continue using police officers for speed control in work zones. Although drivers with CB radios communicated the location and presence of police, the communication did not seem to diminish the effectiveness of police presence on trucks. After the police left the work zone, truck drivers still took the "threat" of police presence seriously and traveled at reduced speeds. Since the halo effect was sustained for trucks, one police officer can be used to control a few adjacent work zones without a significant loss in his/her effectiveness on speed reduction.
REFERENCES


APPENDIX A - EFFECTS OF EXTERNAL FACTORS ON SPEED

Speeds of vehicles during the two days of data collection were affected by what might be called "external factors." The effects of these factors have to be removed from the effects of the police, otherwise a misleading conclusion might be drawn. The external factors are described below:

(1) A flagman was present near Station 2 during control data from 2 to 3 pm.
(2) The flashing lights on the speed limit signs were turned off at different times in the two days of data collection.
(3) Police remained stationed at Station 2 from 12 noon to 1 pm on the treatment day.

The effects of the external factors on the average speed of vehicles are shown in Figures A.1 through A.4. As shown in Figures A.1 and A.2, the speed reduction between Stations 1 and 2 reached its maximum value during the 2 to 3 pm time period because a flagman was near Station 2. Similarly, for the treatment data the reduction is maximum during the 12 to 1 pm time period because the police car was near Station 2 (see Figures A.3 and A.4).

Data for this experiment were collected for several hours, but only the data for the time periods from 11 am to 12 noon, from 1 pm to 2 pm, and from 3 pm to 4 pm were not influenced by the external factors. It was decided not to use the data from 11 am to 12 noon because the police officer arrived at the site at 11 am and drivers' communication delays may be observed within this period. Therefore, for statistical analysis of the police presence effects, the data from 1 pm to 2 pm will be used and, for evaluation of the halo effect the data from 3 pm to 4 pm will be used.

These two time periods have provided a sufficient data sample to perform the necessary statistical analyses. It should be noted that the data for the entire time period will be utilized in various forms, but for the statistical analysis only the data from the aforementioned time periods will be used. Table A.1 shows the periods in which data collected during the two days were affected by the external factors mentioned above.
<table>
<thead>
<tr>
<th>Time Period</th>
<th>External Factors</th>
<th>Police Presence</th>
<th>Flagman</th>
<th>Flashing Lights</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00 - 11:00</td>
<td>Police were in work zone till 11 am on control day</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11:00 - 12:00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12:00 - 1:00</td>
<td>Police stopped near Station 2 on treatment day</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1:00 - 2:00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2:00 - 3:00</td>
<td>-</td>
<td>Present near Station 2 on control day</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3:00 - 4:00</td>
<td>3 pm police left the work zone on treatment day</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4:00 - 5:00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4:00 pm turned off on control day</td>
</tr>
<tr>
<td>5:00 - 6:00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5:00 pm turned off on treatment day</td>
</tr>
</tbody>
</table>
Figure A.1. Speed reductions (mph) for cars in Control Day

Figure A.2. Speed reductions (mph) for trucks in Control Day
Figure A.3. Speed reductions (mph) for cars in Treatment Day

Figure A.4. Speed reductions (mph) for trucks in Treatment Day