I-43 Speed Warning Sign Evaluation

Performed for the
Wisconsin Department of Transportation

By

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FOREWORD

Based on the data we collected in the field, the sign had a speed reduction effect on the drivers that triggered the sign; speeds of all other drivers ("background" speeds) displayed very minor variations between the period before the sign display was operational and the period following sign display unveiling.

Given the sign speed and vehicle weight thresholds in place during this evaluation, 1.8% of the drivers actuated the sign display. More than half of these actuations were related to semi-trucks. Although the emphasis at the outset of this evaluation was placed on larger trucks, an effort was made to collect information on smaller vehicles, as well.

A speed reduction of 3.2 mph at the North Avenue curve in the period following sign unveiling was documented for semi-truck drivers who actuated the sign. Tentative findings for other vehicle sizes are documented in the report.

A special subsection describes the report organization. The body of the report addresses sign speed reduction effect. Supporting information is organized in four appendices. Appendix A presents sign and study site information. Appendix B discusses general traffic and violator characteristics. It contains a number of tables and figures that are introduced and summarized in the self-contained narrative. You may find this information useful in deciding sign threshold values. Appendix C contains all statistics relating to sign speed reduction effectiveness. Appendix text explains where statistics that relate to each of the four tested hypotheses can be found. A detailed explanation of how statistics can be interpreted is presented in the discussion of small vehicle findings on pp. 11-12. Appendix D is a self-contained crash analysis that includes a bullet summary of findings.

I am grateful for the help of Marquette University Graduate students: Sharad Uprety who helped with data collection and Georgia Vergou who helped in the preparation of this report. This work would have not been possible without funding from the Wisconsin Department of Transportation and the help of a great number of WisDOT employees: John Corbin, Mike Hardy, John Mishefske, Don Schell, Dick Lange, Mike Bub; and Brian Scharles of TAPCO Inc.

In reviewing this report, please keep in mind that we had to overcome the following **limitations** :

- No information was available about vehicle classification or speed distribution by vehicle class at the outset of this evaluation.
- Only two weeks were available for "before" data collection; frequent lane closures due to construction and maintenance activities during this period dramatically reduced the opportunities to collect data during hours when free-flow speeds were present.
- Sign thresholds had not been decided during the before period (since no speed data by vehicle class was available on which to base any decisions).
- Our efforts during the before period focused on collecting the largest data samples we could, so we would have adequate sample sizes for vehicles that would exceed any chosen sign trigger speed (sign trigger speeds would be chosen ***following*** our before period data collection).
    - More than 40 field visits were made to download detailed information about each vehicle that crossed the sign detectors: speed, lane, time, vehicle class, GVW was saved for more than a month–CPU memory would overflow in less than 48 hours, if data was not downloaded. (Just 584,512 of these observations were used in Table B3.)
    - We manually collected vehicle information at the curve PC: speed, lane, time and vehicle class for 1,334 vehicles before, and 1,496 vehicles after the sign was unveiled, monitoring one vehicle at a time, using a laser gun, because we trusted the instrument's accuracy, we knew precisely which vehicle we were targeting, and we could set the instrument to monitor speeds at the curve PC (not before, nor after that point).

- The original goal of this evaluation, to compare average and 85th percentile speeds at the curve PC before and after sign operation, was abandoned when it became obvious that only 1.8% of the traffic triggered the sign: targeted traffic speeds would not have a noticeable effect on the remaining 97.2% of the traffic, even if the sign induced drivers to slow down by 10 mph in the after period.
- The remaining option was to manually match the speeds of 31,151 vehicles that crossed the sign detectors during our field data collection efforts, with the 2,830 vehicles that we observed at the PC (using the laser gun) during these times. Fortunately, we had detailed information for each vehicle–this task was extremely time-consuming, but provided the best evidence of sign effectiveness:
    - **Although the sign addressed just 1.8% of all traffic, our chosen method showed unequivocally that the sign had an effect on speeds**; the method also showed that speeds of drivers who did not see the sign activated remained unchanged for all analyzed vehicle classes.
    - The added benefit of collecting this detailed database is that the number of drivers within any given vehicle class that exceeded any given speed at any day of the week or any time of the day is precisely known for the before period. If new sign speed thresholds are decided in the future, the number of would-be violators and their average speeds at the detector and the PC in the before period can be accurately calculated and compared with the violator statistics corresponding to the new sign threshold settings.

I hope you find this report useful and informative. Please do not hesitate to contact me by telephone at (414) 288 5430 or by e-mail at Alexander. Drakopoulos@Marquette.edu

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ABSTRACT

An excessive speed warning device was installed on a sign bridge over the southbound lanes of I-43 in Milwaukee County, between the Wright Street and the North Avenue overpasses. The device has the ability to detect the vehicle class, speed and weight of vehicles approaching in a particular lane. If an approaching vehicle exceeds (violates) preset maximum speed and weight thresholds for its vehicle class, the message "TOO FAST FOR CURVE" is illuminated over the lane in which the violating vehicle was detected. The message remains illuminated for a few seconds, after which the sign face remains blank, until another violating vehicle is detected.

The purpose of the installed device was to induce speeding drivers to reduce their speeds before entering the North Avenue curve, identified as a site of numerous speed-related crashes. The speed limit was 50 mph which was also the curve design speed. The sign bridge was installed 345 feet upstream of the curve point of curvature. System detectors were embedded in the pavement 860 feet before the curve where vehicular information was gathered and evaluated in relation to sign thresholds.

Sign evaluation was based on a before-after (sign operation) speed comparison at the curve point of curvature (PC) where a total of 2,830 speed observations were gathered. The sign display was inoperative and veiled, but system detectors were operational during the before period. Information on 584,512 vehicles was recorded by the detectors during the before and after periods.

Background speeds remained unchanged at the study site in the period following sign unveiling. Speeds at the PC were lower by 3.2 mph for semi-trucks who activated the sign (this speed change was statistically significant at the 0.05 level of significance, with a 95% confidence interval of 2.5 to 3.9 mph). Speed reductions were also identified for small vehicles (autos, pickup trucks, vans and SUVs) and single-unit trucks and buses, but these findings were tentative because they were based on very small data samples.

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INTRODUCTION

An excessive speed warning device was installed on a sign bridge over the southbound lanes of I-43 in Milwaukee County, between the Wright Street and the North Avenue overpasses. The device has the ability to detect the vehicle class, speed and weight of vehicles approaching in a particular lane. If an approaching vehicle exceeds (violates) preset maximum speed and weight thresholds for its vehicle class, the message "TOO FAST FOR CURVE" is illuminated over the lane in which the violating vehicle was detected. The message remains illuminated for a few seconds, after which the sign face remains blank, until another violating vehicle is detected.

The purpose of the installed device was to induce speeding drivers to reduce their speeds before entering the North Avenue curve, identified as a site of numerous speed-related crashes. The sign bridge was installed 345 feet upstream of the curve point of curvature. System detectors were embedded in the pavement 860 feet before the curve where vehicular information was gathered. This detector placement provided sufficient time for sign actuation, driver perception-reaction (to sign message), and deceleration, even for the fastest drivers in the traffic stream.

System selection was based on a thorough comparison of benefits and disadvantages of a variety of speed reduction technologies. The evaluated system was chosen for its affordability, reliability, low maintenance costs, and sophistication that would allow WisDOT to set individual speed and weight criteria for each vehicle class.

REPORT ORGANIZATION

The first sections of the report address the general topics of study purpose, system description and evaluation site description. The evaluation description section introduces the study periods and the four hypotheses addressed in the evaluation. This is followed by a brief section on data collection objectives and more extensive information on when, how and where speed data were collected, in the data collection methodology section.

The data analysis section addresses speed- and crash-related findings in separate subsections. The subsection addressing speed findings describes in detail how statistics were used to provide answers to the four hypotheses addressed in the evaluation, for each of three vehicle types. Partial summaries of the most important findings are presented for each vehicle type; an overall summary is provided at the end of the subsection. The crash analysis subsection presents a summary of information that is extensively covered in Appendix D.

A brief presentation of all findings is presented in a separate section, followed by a discussion on issues relating to setting sign thresholds and recommendations.

Appendices provide detailed information that was separated from the body of the report, in order to preserve text continuity.

Appendix A contains sign dimensional details and miscellaneous study site information presented on aerial photographs.

Appendix B presents the vehicle classification scheme used by the evaluated system as well as speed and violation information presented separately for weekdays and weekends. The appendix introduction summarizes information presented in figures and tables.

Appendix C contains information pertaining to sign speed reduction effectiveness. Data collection hours and sample sizes, sign threshold values and violation percentages during these hours are presented in separate tables. The rest of the appendix contains speed statistics categorized by period (before or after), location (at the detectors or at the PC) and whether a driver was speeding or not (violator or non-violator).

Appendix D contains a crash analysis based on crash rates and crash frequencies. Separate information on small and large vehicles is provided where possible. The narrative summarizes information presented in figures and tables at the end of the appendix. An itemized list of findings concludes the narrative part of the appendix.

An effort was made throughout the report to provide as much detail as was practical. For example, although system detectors identified vehicles belonging to 12 vehicle classes, vehicle classes were collapsed into four vehicle "categories" in Appendix B for ease of presentation. Vehicle categories had similar sign threshold speeds and included the most prevalent vehicle classes in the traffic stream (98.8% of all vehicles were included).

It was necessary to reduce the four vehicle "categories" of Appendix B to three vehicle "types" in the speed analysis in Appendix C, because the available number of observations was much smaller for that analysis. However, this was done by simply collapsing two vehicle categories into one vehicle type, allowing comparisons between data in the two appendices. The same terms were used for the two vehicle sets that were present in both summaries ("Small vehicles" and "Semi-trucks").

Only two vehicle "sizes" were used in the crash analysis (Appendix D) because there were too few crash records for a more detailed large vehicle presentation. The term "Small vehicles" remained; all other vehicle classes were included under "Large vehicles."

Because speeds at the detectors showed very minor change between the before and the after period, all speeds are presented together in Appendix B.

For easier Appendix B figure readability, the same color was used for a given vehicle category (e.g., red for small vehicles) in stack bar, line and cumulative distribution figures.

STUDY PURPOSE

The purpose of the evaluated device was to reduce southbound speed-related crashes at the I-43 freeway North Avenue curve. This would be accomplished by selectively displaying the message “TOO FAST FOR CURVE” to drivers that were the most likely to be involved in a speed-related crash (faster drivers driving heavier vehicles) within each vehicle class. Targeted drivers were expected to slow down as they approached the curve.

If the sign was effective, there would be fewer speed-related crashes in the period following sign installation. However, because accumulating adequate statistics for a statistically valid evaluation of crash experience would require a few years of post-sign installation crash experience, the present evaluation focused on sign speed-reduction effects, which could be evaluated immediately after sign operation. If the sign was effective, speeds of violators (drivers exceeding the speed and weight sign thresholds for their vehicle’s class) would be lower at the study curve in the period following sign installation. Such a speed reduction would be reasonably expected to result in a lower number of speed-related crashes.

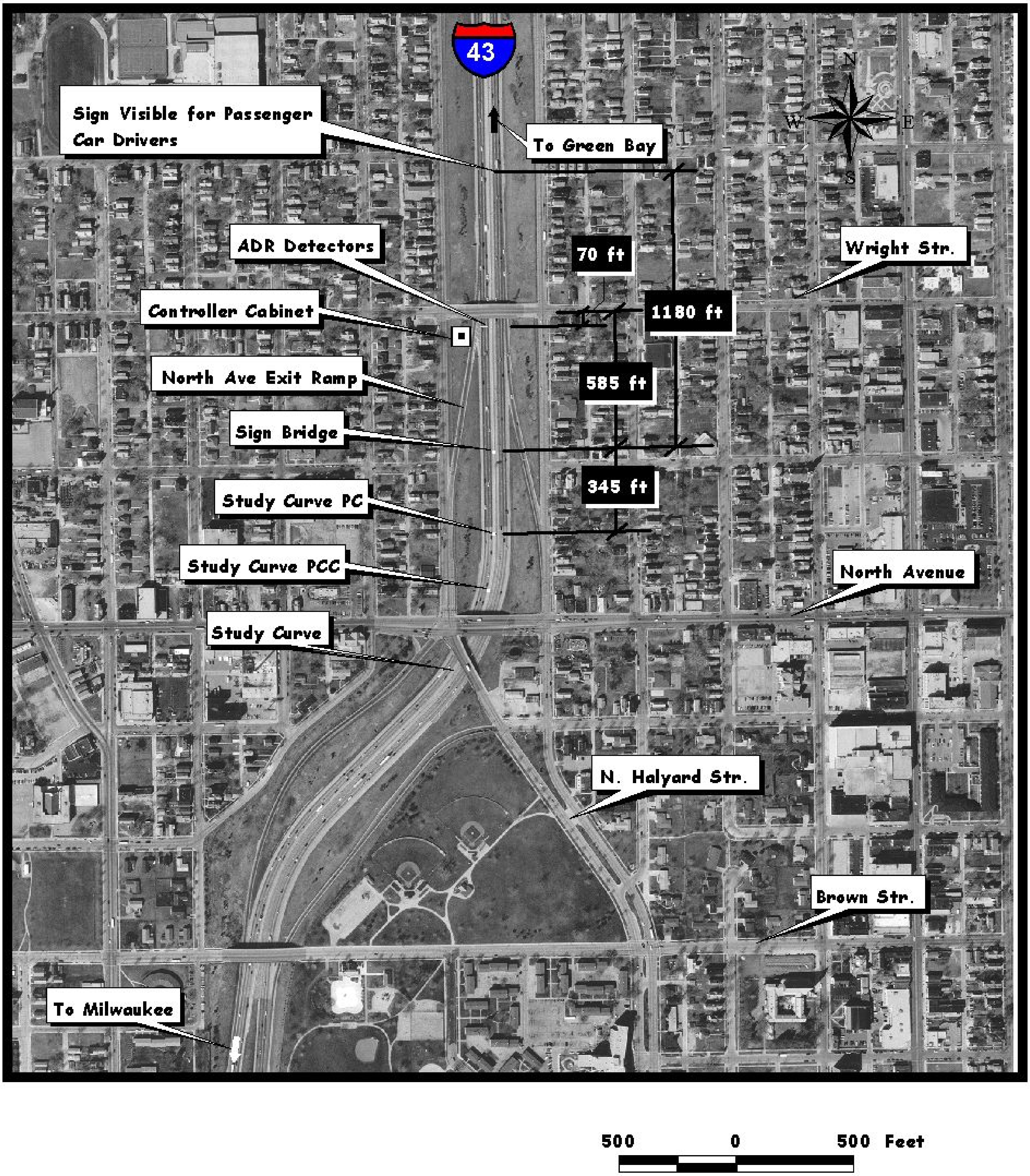
An analysis of historical crash experience was performed in order to identify crash characteristics at the study location. The purpose of this analysis was to gain a better understanding of speed-related crashes, and their prevalence among large and small vehicles.

SYSTEM DESCRIPTION

The installed system consists of a controller cabinet containing the Central Processing Unit (CPU), connected to pavement-embedded detector arrangements and to signs placed over the freeway (one per lane), on a sign bridge. Each detector arrangement is capable of identifying vehicle weight, and speed as well as vehicle class for each vehicle traveling in a particular lane. This information is sent to the CPU where it is processed and compared against preset speed and Gross Vehicle Weight (GVW) criteria, specific for each vehicle class. If both the preset speed and GVW criteria are exceeded for a detected vehicle (if a “violation” is detected), the CPU activates the indication “TOO FAST FOR CURVE” and two yellow flashers over the lane the vehicle is moving in. The indication is turned off after a few seconds and is activated again when a subsequent violator is detected. The locations of the controller cabinet, detectors and sign bridge are shown in **Figure 1**.

Detailed engineering drawings of the sign bridge and the sign face are provided in **Figures A1 and A2**, respectively.

Figure 1. Study Site.



SITE DESCRIPTION

The targeted study curve follows a segment of at least 8,000 feet that is mostly tangent, except for two curves with very small curvatures, located near its north end (see **Figure A3**). Detailed traffic composition, traffic volume and speed information is presented in **Appendix B**, the source of information presented in this section.

SIGNS

The speed limit approaching the study location is 55 mph. A reduced speed sign for 50 mph is located 1910 feet from the study curve point of curvature (PC), followed by a 50 mph speed limit sign at 1375 feet from the PC. An advisory 50 mph speed limit sign and a curve to the right sign are mounted on the median, 575 feet from the PC; a 50 mph speed limit sign is posted on the right-hand side at the same location. "Tippy truck" signs are mounted on either side of the sign bridge, 345 feet before the curve PC, and a "minimum speed 40 mph" sign is mounted on the median at the PC. The exact locations and types of speed-related and curve warning signs, are depicted on **Figure A4**.

DETECTORS

Sign detectors are located 860 feet before the PC (**Figure 1**). Separate pavement-embedded detector sets are placed within each lane of travel. Each set consists of two loop detectors with a piezo-electric sensor between them. This arrangement has the capability of determining vehicle class, speed and weight.

GEOMETRY AND DESIGN SPEED

Curve geometry is shown in detail in **Figure A5**. Given a radius of 1,000 feet, and a maximum superelevation of 8%, the design speed is 55 mph.[1]

TRAFFIC VOLUMES

The southbound direction carries approximately 65,000 vpd in three lanes of mainline traffic. The median and the middle lane carry 35% of the daily traffic each; the shoulder lane carries the remaining 30% of the traffic. Weekday mornings, traffic peaks between 7:00 am and 8:00 am at 5,600 vph; afternoon peak volumes between 5:00 pm and 6:00 pm are 4,150 vph. Weekend volumes do not exceed 3,500 vph.

TRAFFIC COMPOSITION

During weekdays, 93% of the traffic consists of passenger cars, vans, and pickup trucks (including SUVs). Semi-trucks are 4% and single-unit trucks (including buses) are 2% of the traffic. Weekend traffic is 97% small vehicles, with trucks at half their weekday levels.

TRAFFIC SPEEDS

Measured at the detectors: Weekday speeds drop to about 48-50 mph during the am and pm peak hours; it is important to note that lower speeds during the afternoon do not coincide with the highest traffic volumes—they are due to congestion downstream of the study site, and occur between 3:00 pm and 4:00 pm. Average midday speeds are 58 mph

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[1] A Policy on Geometric Design of Highways and Streets, Fourth Edition, 2001, AASHTO.

for small vehicles, and 2 mph lower for trucks. Approximately 15% of the traffic drives at or below the speed limit of 50 mph; 85th percentile speeds are between 58 and 61 mph, with small vehicles at the high end of speeds and trucks at the low end.

Small vehicle weekend speeds range between 58 and 60 mph between 5 am and 8 pm. Semi-truck speeds are approximately 2 mph lower during these hours. Approximately 2% of speeds are at or below the speed limit; 85th percentile speeds range between 58 and 64 mph, depending on vehicle size in a fashion similar to weekdays.

EVALUATION DESCRIPTION

The present evaluation is a speed comparison "before-and-after" sign installation. "Before" data was collected between September 1 and September 15, 2002. During this period the sign bridge was in place, with each of the three sign faces veiled. Sign threshold criteria (**Table C2**) were loaded into the CPU on September 13, and sign unveiling took place on September 16. "After" period data was collected between September 22 and September 29, 2002. If the evaluated system was effective, lower speeds would be expected at the study curve in the period following sign unveiling.

Speed data at the study curve were collected manually on selected dates during the before and the after period, using a laser gun. The point of curvature (PC) of the study curve was chosen as a suitable location to collect curve speeds, since vehicles were subjected to centrifugal force at this point, as they started to travel on a circular path, while they still had their highest speeds along the curve (assuming drivers were driving at a constant speed or decelerated as they approached the curve), and maximum superelevation was not yet fully attained. Thus, the PC was more disadvantageous to vehicle stability than, say, the middle of the curve; speeds at the PC were more likely to be related to the potential for speed-related crashes.

Although the focus of the analysis was speeds at the PC after sign unveiling, vehicle information collected through the detectors, located 860 feet before the PC, was also critical for the evaluation. It provided continuous study site background information, such as violator statistics and hourly volume and speed distributions for each vehicle class during the days analyzed herein.

The basic hypothesis tested in the speed analysis section, was that speeds at the PC in the after period were lower than speeds at the PC in the before period, as a result of sign operation. In addition to examining speed changes at the PC, it was necessary to ascertain that speeds of drivers who did not trigger the sign remained unchanged following sign unveiling.

Because the sign was actuated only by drivers whose vehicles exceeded sign speed and weight criteria for their vehicle class (violators), sign-related speed reduction at the PC was expected to be evident only among violators; speeds of non-violators at the PC were expected to remain unchanged in the after period. Taking into account that determination of whether a driver was a violator or not took place at the detector location, a couple of seconds ***before*** the sign was activated, speeds of **all** drivers (violators and non-violators) at the detectors were expected to remain unchanged.

If all above-stated hypotheses were true, that is, if in the after period:[2]

H_1: Violator speeds at the PC were lower;
H_2: Non-violator speeds at the PC remained unchanged;
H_3: Violator speeds at the detectors remained unchanged; and,
H_4: Non-violator speeds at the detectors remained unchanged,

then one could be assured that speed changes at the PC were the result of sign operation, and that no other factors affected speeds at the study location during the after period. Thus, all four hypotheses needed to be satisfied in order to definitively conclude that the sign was effective.

The possibility existed that there would be a "spill-over" sign effect on drivers who did not activate the sign, who happened to be in the vicinity of the sign when it was activated by a violator. In that case, a speed reduction could also be expected in the after period instead of the "remained unchanged" part of hypotheses **H_2**, **H_3** and **H_4**. Based on field measurements, the sign was visible to passenger car drivers at a distance of 1,180 feet from the sign bridge, as shown in **Figure 1**, if no obstructions, other than the Wright Str. bridge were blocking their view.

Because different speed and weight sign thresholds were used for different vehicle classes, sign effect would have to be evaluated separately for each vehicle class, however, the emphasis at the outset of the present study was on larger trucks (semi-trucks).

DATA COLLECTION OBJECTIVES

Data collection during the "before" period served the dual purpose of:

1. Establishing a speed baseline for sign speed reduction effectiveness evaluation; and,
2. Providing accurate speed information for each vehicle class, so reasonable sign threshold values could be set.

Data collection during the "after" period provided information necessary to evaluate the four hypotheses listed above.

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[2] The implicit alternate hypotheses were:

H_{1A}: Violator speeds at the PC remained unchanged or were higher;
H_{2A}: Non-violator speeds at the PC changed;
H_{3A}: Violator speeds at the detectors changed; and,
H_{4A}: Non-violator speeds at the detectors changed.

DATA COLLECTION METHODOLOGY

Data were collected at the detector location, using the installed system's CPU, and manually, at the PC, using a laser gun. The before time period available for data collection was limited by the system installation date and the decided system unveiling date. Field data collection opportunities were often limited by lane closures, maintenance activities and various incidents. Field data collection hours were chosen taking into account the competing objectives of choosing hours during which enough violations occurred for a productive data collection effort, but avoiding hours during which higher traffic volumes resulted in lower speeds. Field data was collected during the hours following weekday morning peaks and early Sunday mornings.

Lacking detailed vehicle classification and speed information for each vehicle class at the outset of this evaluation, data collection hours were selected based on total hourly volume and average speed information. Data collection days and times used in the before period determined when data would be collected during the after period: it was desirable to collect data during the same days and similar hours, in order to avoid day-of-week and time-of-day speed biases. A detailed listing of data collection dates and times is provided in **Table C1**.

SPEEDS AT THE PC

It was decided to use a laser gun for field speed data collection, because of the superior instrument accuracy, and ability to target specific vehicles. PC speed data was collected from the Wright Street bridge. The observation location on the south face of the bridge above the middle lane, provided a direct line of sight to the PC, and was completely hidden from drivers. Two observers were involved: one would obtain the laser gun measurements, and the other would record this information. Lane and vehicle class information and whether the recorded vehicle had actuated the sign[3] was dictated by the first observer.

A total of 2,830 observations were collected during field data collection hours listed in **Table C1**.

SPEEDS AT THE DETECTORS

Individual vehicle information (lane, vehicle class, speed, weight, time, date) collected through system detectors was stored in the field and downloaded to laptop computers for processing in the office. Field memory was adequate to store data for two 24-hour periods at a time.

A total of 584,512 observations were collected during the days field data was also collected. 31,151 of these observations corresponded to the hours that laser gun data was collected, listed in **Table C1**.

[3] Sign actuation information was available in the field only during the after period. The sign was veiled during the before period; final sign threshold values were not uploaded until September 13, 2002.

EQUIPMENT RELIABILITY CHECKS

Two separate checks were performed in order to guarantee the validity of the collected speed data:

- Speed and vehicle class information recorded by system detectors was checked using the laser gun. Detectors were found to operate accurately in each lane.
- The time between vehicle passage over system detectors and sign actuation was measured and was found to be adequate to allow drivers time to read the sign message. (Actuation required no more than 2.0 seconds—a vehicle traveling at 90 mph would cover the distance between detectors and sign in 3.9 seconds).

DATA ANALYSIS

SPEEDS

Speed data analyzed here were collected through: **i)** system **detectors**, located on a tangent, 860 feet upstream of the PC; and, **ii)** a laser gun, used to collect speeds at the **PC**. The speeds of all vehicles passing over the detectors were recorded; speeds were captured at the PC for only a sample of these vehicles. The analysis presented herein refers to data collected at these two locations during the time periods listed in **Table C1** (hours laser gun data were collected).

If the sign was effective in reducing vehicular speeds at the PC, and speeds remained unaffected by external factors, the following hypotheses would be true in the after period:

H_1: Violator speeds at the PC were lower;
H_2: Non-violator speeds at the PC remained unchanged;
H_3: Violator speeds at the detectors remained unchanged; and,
H_4: Non-violator speeds at the detectors remained unchanged.

Ideally, each of these hypotheses would be examined for each individual vehicle class. However, collecting an adequate sample of speeds at the PC for each vehicle class exceeded the resources available for this effort. Thus, vehicle classes were collapsed into three vehicle types (**Table 1**) in order to have adequate numbers of observations for analysis within each vehicle type. Each vehicle type includes vehicle classes with identical or nearly-identical sign speed threshold values (see **Table C2** for sign threshold values).

Table 1. Vehicle Classes Included in Each Vehicle Type.

Vehicle type	Vehicle classes
1 Small vehicles	2,3
2 Single-unit trucks	4,5,6,7
3 Semi-trucks	8,9

Note: The term "Single-unit trucks" is used for brevity. This vehicle type includes all vehicles larger than a pick-up truck, and smaller than a combination vehicle, including buses. A comprehensive listing of vehicle classes can be found in **Table B1**.

Figures 2 - 4 present information about speeds at which drivers crossed the detector location and the speeds at which they entered the curve PC. The speed at which a driver crossed the detector location, in combination with gross vehicle weight determined whether the sign would be activated (the driver was a "violator") or not. Each figure presents statistics separately for drivers that exceeded sign threshold values as they crossed the detectors (violators) and those who did not (non-violators), at the detector location and at the PC, before and after sign unveiling/activation.

The figures indicate the 95% confidence intervals for mean speeds. The left half of each figure indicates "before" period statistics, and the right half "after" period statistics. Within each period, a pair of speeds at the detectors is followed by a pair of speeds at the PC. The number of observations used to calculate each of the eight means is shown along the horizontal axis.

Although the sign display was veiled and inoperative during the before period, it was possible to identify which among drivers during that period would have triggered the sign. This was done based on sign threshold values, because speeds and vehicle weights were recorded for each vehicle that crossed the detectors, which were operational throughout the evaluation period. Once these drivers were identified, it was possible to manually match their speeds at the detector with their speeds at the PC, based on lane, vehicle type and time information.

Sign threshold values were established based on before period information captured by the detectors. These thresholds, listed in **Table C2**, were uploaded to the system CPU on September 13, 2002, before sign unveiling. Although the number of observations at the PC is relatively large for each analyzed vehicle type, the number of violators whose speeds were captured at the PC in the before period is small for small vehicles and single-unit trucks. This is due to the smaller percentages of violators among these vehicle types (Row% – **Table B3**); and/or the smaller percentage of these vehicles in the traffic stream; and the inability to identify violators in the field during the before period. Ideally, 30 or more observations were required for valid statistics for each of the eight means in **Figures 2 – 4**.

An extensive presentation of violator and non-violator hourly speeds for various vehicle categories can be found in **Appendix B**.

The presentation of small vehicle findings below, provides a detailed interpretation of the information furnished through each of **Figures 2 - 4** and **Appendix C** tables. Only summary information is presented for single-unit truck and semi-truck findings.

Important Statistics Caution

Ideally, there should be at least 30 observations for valid statistics based on each of the eight means shown in Figures 2 – 4. Adequate sample sizes were not available for violator speeds at the PC for: small vehicles and single-unit trucks during the before period; also for single-unit trucks during the after period. Any statistics involving these three data sets should be viewed as tentative only. All other data sets had adequate observations. Sample sizes are presented in **Figures 2-4**; also **Tables C4, C6** and **C8**.

Small Vehicles

The effect of sign activation on small vehicle (auto, pickup truck, van and SUV) speeds is summarized in **Figure 2.** The speed trigger value was set at 70 mph for these vehicles.

It should be emphasized that the sample size for **violator speeds at the PC in the before period is too small for valid statistics (n = 7)**; all other sample sizes are adequate. Thus statistics on any comparisons to violator speeds at the PC in the before period should be viewed as tentative, at best.

It is interesting to note in **Figure 2** that non-violator speeds (triangular markers) were virtually identical at the detectors and the PC, both in the before and the after period (58 mph). However, violators (circular markers), decelerated between the detectors and the PC. Although violators crossed the **detectors** at approximately the same speed in both periods (72 mph), their **average speed reduction** by the time they crossed the PC was different during the before and the after period (3.3 mph and 9.3 mph, respectively). This was the only measured speed change in the after period. It was only evident for violators, who saw the sign activated (a couple of seconds *after* they had crossed the detectors, *only* in the after period). Thus, the speed reduction change observed for violators at the PC (from 3.3 to 9.3 mph) in the after period, can be directly attributed to sign operation.

The preceding information was based on the 95% confidence intervals for **average** observed speeds shown in **Figure 2,** which provides a succinct presentation of findings. The same findings are listed in numeric format in **Table C4**. Speed **differences** between the eight averages shown in **Figure 2**, their statistical significance and their 95% confidence intervals are summarized in **Table C5**; differences shown in **bold type** provide statistical information for the four hypotheses tested in this section ($\mathbf{H_1}$ through $\mathbf{H_4}$).

Table C5 indicates that the difference "speed at the PC before –speed at the PC after" for violators (hypothesis $\mathbf{H_1}$) was 6.4 mph and was statistically significant at the 0.05 level of significance (significance level 0.000). The 95% confidence interval for this speed change was between 2.8 and 10.0 mph. In what follows this information will be abbreviated to "***sig****., 95%CI* 2.8 to 10.0 mph." Thus, hypothesis $\mathbf{H_1}$ "violator speeds at the PC were lower in the after period," is true—speeds ***were*** lower by 6.4 mph, on average. One can be sure (with a less than 1/1000 chance of error) that the before and after speed samples came from speed distributions with different average speeds. One can further be 95% sure that the difference in average speeds between the before and the after speed distributions was between 2.8 and 10.0 mph (if 100 speed samples were available, average speed differences for 95 of these samples would be within this range).

Table C5 indicates that hypothesis **H_2** "non-violator speeds at the PC remained unchanged in the after period" cannot be rejected at the 0.05 level, given a significance level of 0.824. In other words, one can be 82% sure that the before and after speed samples came from speed distributions with the same average speed. Average speed change was –0.047 mph[4] with a 95% confidence interval between –0.5 and 0.4 mph (***non-sig.,*** *95%CI* –0.5 to 0.4 mph).

Similarly, **H_3** (violator speeds at the detectors remained unchanged in the after period) and **H_4** (non-violator speeds at the detectors were unchanged in the after period) could not be rejected at the 0.05 level of significance--(***non-sig.,*** *95%CI* –0.9 to 1.8 mph) and (***non-sig.,*** *95%CI* –0.1 to 0.1 mph), respectively.

Summary: It was shown that small vehicle violator speeds at the PC were lower following sign installation. This is a **tentative** finding, given the **very** small sample of speeds during the before period. Speeds at the detector location remained unaffected for all drivers, as did speeds of non-violators at the PC. These findings are based on adequate sample sizes and can be trusted. Thus, the definitive conclusion of this analysis was that background speeds remained unaffected after sign unveiling.

Sign installation induced an average speed reduction of 6.4 mph among violators at the PC; although this speed change was statistically significant at the 0.05 level of significance, its 95% confidence interval was quite broad, ranging between 2.8 and 10.0 mph, due to the small number of violator observations for this vehicle type. Statistical findings for the four tested hypotheses are presented in **Table 2** below.[5]

Table 2. Small Vehicle Mean Speed Differences (mph).

Test	(I) Period, Location, Violator	(J) Period, Location, Violator	Mean (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
H_1	Before @ PC Viol	After @ PC Viol	6.401*	1.8264	.000	2.821	9.981
H_2	Before @ PC Non-Viol	After @ PC Non-Viol	-.047	.2116	.824	-.462	.368
H_3	Before @ Detector Viol	After @ Detector Viol	.456	.6824	.504	-.882	1.793
H_4	Before @ Detector Non-Viol	After @ Detector Non-Viol	-.043	.0526	.413	-.146	.060

Based on observed means.
* The mean difference is significant at the .05 level. **This finding is based on a very small sample for the before period (n= 7).**

[4] The negative sign indicates higher speeds in the after period.
[5] Information extracted from Table C5.

Single-Unit Trucks
The effect of sign activation on single-unit trucks (classes 4-7) is summarized in **Figure 3**. Speed trigger values were set at 62 mph for classes 4 and 5 and at 60 mph for classes 6 and 7.

Unlike non-violators among small vehicle drivers, who did not decelerate as they approached the curve, **Figure 3** indicates that non-violators among single-unit trucks (triangular markers), reduced their speeds from 54.6 mph to 53.4 mph in both periods (**Table C6**) as they approached the PC. A much more pronounced speed reduction was evident for violators approaching the curve (filled round markers). That speed reduction was 1.8 mph in the before period (***non-sig.***, *95%CI* -3.0 to 6.5 mph), and 8.0 mph in the after period (***sig.***, *95%CI* 5.2 to 10.9 mph). Average violator speeds at the PC were 5.1 mph lower in the after period (***sig.***, *95%CI* 0.1 to 10.1 mph). The wide 95% confidence interval for this speed reduction was due to the small number of observations in both periods.

Summary: Findings regarding the four tested hypotheses of interest are summarized in **Table 3** below: It was **tentatively** (because of the **very small** violator sample sizes at the PC) shown that violator speeds were lower by 5.1 mph at the PC in the after period, a statistically significant speed change, with the caveat of a very wide 95% confidence interval (0.1 to 10.1 mph see $\mathbf{H_1}$ row) due to the small number of observations. Non-violator speeds did not change at the PC ($\mathbf{H_2}$); violator and non-violator speeds did not change at the detector location ($\mathbf{H_3}$ and $\mathbf{H_4}$). Thus, findings for single-unit trucks indicated that the **tentatively** detected statistically significant average speed reduction of 5.1 mph was due to sign operation.

Table 3. Single-Unit Truck Mean Speed Differences (mph).

Test	(I) Period, Location, Violator	(J) Period, Location, Violator	Mean (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
$\mathbf{H_1}$	Before @ PC Viol	After @ PC Viol	5.133*	2.5509	.044	.130	10.137
$\mathbf{H_2}$	Before @ PC Non-Viol	After @ PC Non-Viol	-.037	.5685	.948	-1.152	1.078
$\mathbf{H_3}$	Before @ Detector Viol	After @ Detector Viol	-1.132	1.2082	.349	-3.502	1.238
$\mathbf{H_4}$	Before @ Detector Non-Viol	After @ Detector Non-Viol	-.040	.3122	.899	-.652	.573

Based on observed means.
* The mean difference is significant at the .05 level. **This finding is based on small sample sizes for the before and the after period.**

Semi-trucks
The effect of sign activation on semi-trucks is summarized in **Figure 4**. Speed trigger values were set at 58 mph and 57 mph for classes 8 and 9 respectively.

Similar to findings for single-unit trucks, non-violator semi-truck drivers reduced their speeds by 1.6 mph in the before period and 1.9 mph in the after period as they approached the PC (both speed changes were statistically significant). Violators reduced their speeds by 2.5 mph (***sig.***, *95%CI* 1.8 to 3.1 mph) in the before period and by 6.0 mph (***sig.***, *95%CI* 5.4 to 6.5 mph) in the after period.

Summary: Table 4 summarizes findings for semi-trucks. Violator speeds at the PC were lower by 3.1 mph in the period following sign unveiling, a statistically significant speed reduction (**H_1**). Non-violator speeds did not change at the PC in the after period (**H_2**), neither did violator speeds at the detector location (**H_3**). Non-violator speeds at the detector increased by 0.6 mph in the after period (**H_4**). Sample sizes were adequate for valid statistics on all hypotheses.

Table 4. Semi-Truck Mean Speed Differences (mph).

Test	(I) Period, Location, Violator	(J) Period, Location, Violator	Mean (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
H_1	Before @ PC Viol	After @ PC Viol	3.191*	.3597	.000	2.485	3.896
H_2	Before @ PC Non-Viol	After @ PC Non-Viol	-.346	.2918	.236	-.918	.226
H_3	Before @ Detector Viol	After @ Detector Viol	-.273	.2772	.325	-.816	.271
H_4	Before @ Detector Non-Viol	After @ Detector Non-Viol	-.633*	.1764	.000	-.979	-.287

Based on observed means.
* The mean difference is significant at the .05 level.

Summary of Speed Findings

Violator speeds at the PC were found to be statistically significantly lower for all analyzed vehicle types in the period following sign unveiling (**Table 5**). Speeds were lower, on average, by 6.4 mph for small vehicles, 5.1 mph for single-unit trucks (including buses), and 3.1 mph for semi-trucks. The 95% confidence intervals for these findings should be kept in mind: they are broad for small vehicles (2.8 to 10.0 mph) and single-unit trucks (0.1 to 10.1 mph), and narrower for semi-trucks (2.5 to 3.9 mph). **Sample sizes were inadequate for small vehicles and single unit trucks.**

Findings for semi-trucks were the best-established among the three analyzed vehicle types, supported by sufficient violator speed sample sizes. Sample sizes for small vehicles and single-unit trucks are based on inadequate sample sizes (less than 30 observations) for valid statistics.

Table 5. Violator Speed Reduction at the PC Due to Sign.

Vehicles	Mean Speed Reduction (mph)*	95% Conf. Interval	
Passenger Cars, Vans, Pickup trucks, SUVs	6.4	2.821	9.981
Single-Unit Trucks and Buses	5.1	0.130	10.137
Semi-trucks	3.2	2.485	3.896

* All speed reductions were significant at the 0.05 level of significance. **Only semi-truck findings are supported by adequate sample sizes.**

Figure 2. Before/After Speed Change

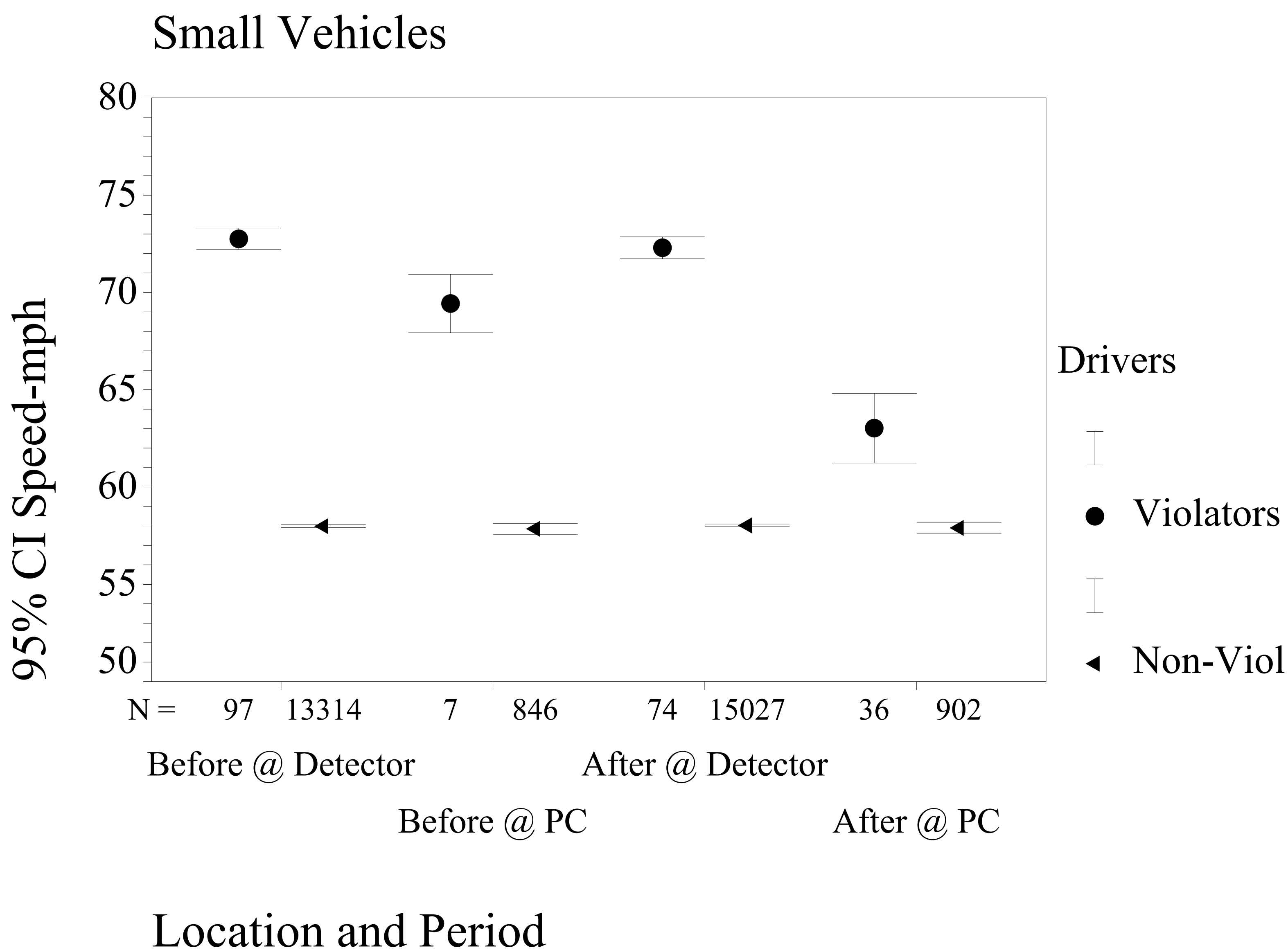


Figure 3. Before/After Speed Change

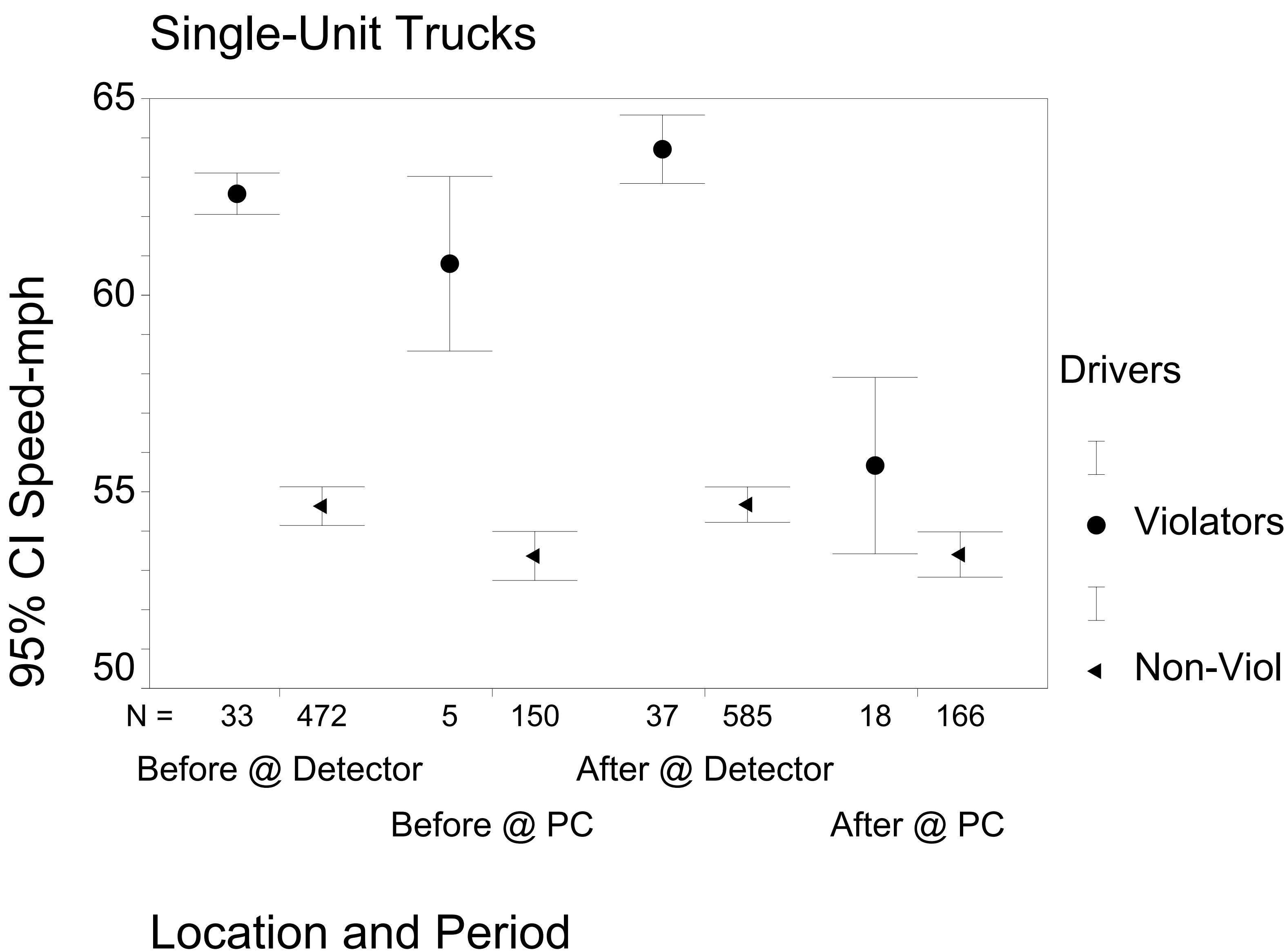
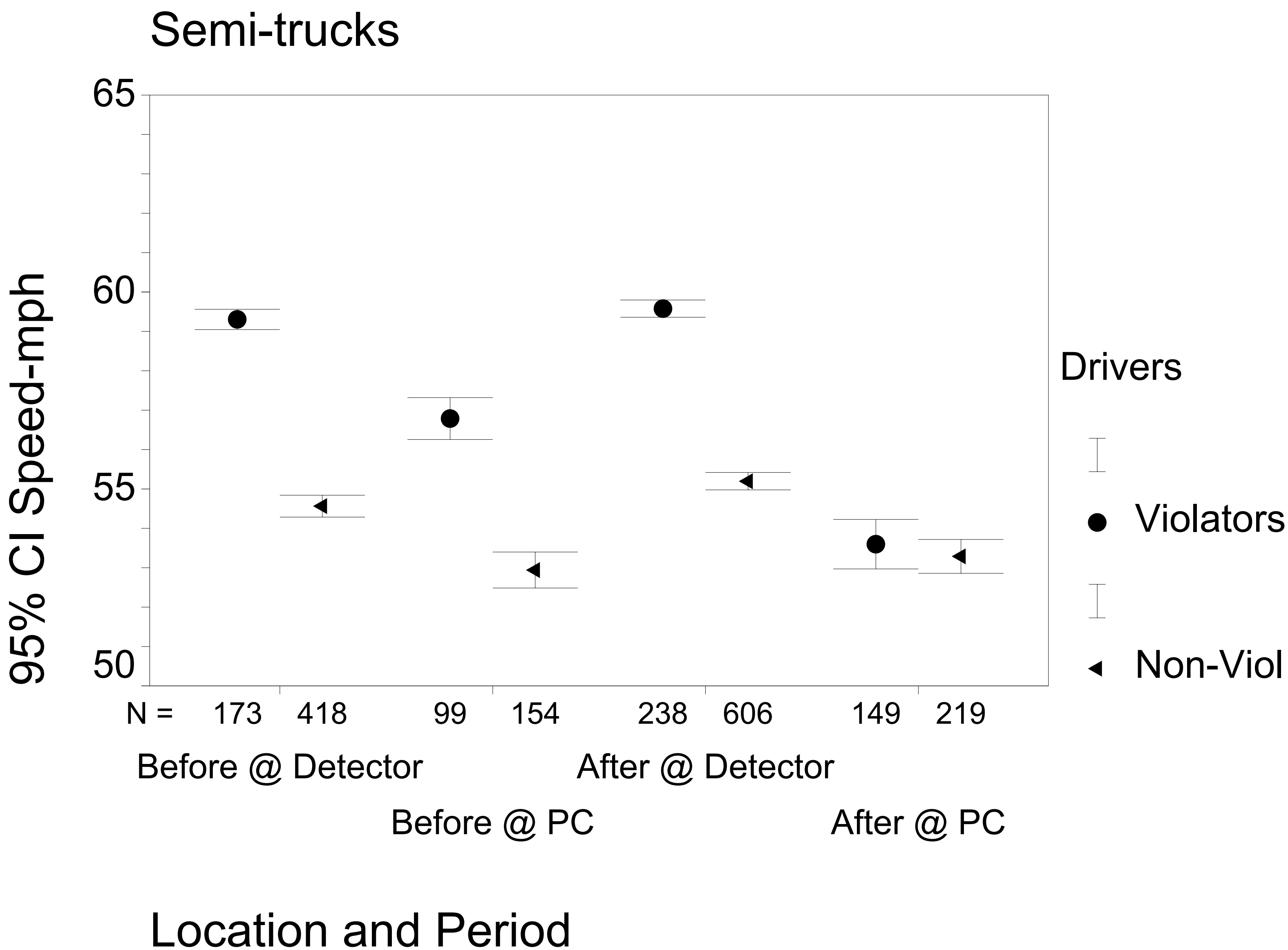


Figure 4. Before/After Speed Change



Background influences on traffic speeds (tested by hypotheses $\mathbf{H_2}$, $\mathbf{H_3}$ and $\mathbf{H_4}$) were found to be non-statistically significant[6] either at the detector site or at the PC for all analyzed vehicle types. Thus, violator speed reduction findings in **Table 5**, do not need to be adjusted to account for background speed changes.

The only exception to background speed findings was for non-violators among semi-truck drivers, whose speeds increased by 0.6 mph at the detector site in the after period ($\mathbf{H_4}$). This speed change was small; it lead to an underestimation of sign effectiveness on violators, producing more conservative results than would have been expected if speeds remained unchanged.[7]

All findings for $\mathbf{H_2}$, $\mathbf{H_3}$ and $\mathbf{H_4}$ were based on adequate sample sizes for all analyzed vehicle types.

CRASHES

A detailed analysis of crash characteristics is presented in **Appendix D**. Speed-related crashes represented two-thirds of all crashes at the study site. Large vehicles, were involved in 16% of these crashes; their presence in the traffic stream was 7% on weekdays and 3% on weekends (5.9% overall). Furthermore, the large vehicle crash rate for speed-related crashes was three times higher than the small vehicle crash rate. Thus, although the majority of speed-related crashes involved small vehicles only, attention in reducing large vehicle involvement in such crashes was warranted, given that they were involved in disproportionate numbers to their presence in the traffic stream.

The majority of speed-related crashes occurred on wet pavement (84%); four-fifths occurred under dark-lighted conditions. The majority of injury crashes (70%) were speed-related.

Speed-related crashes during weekdays peaked during midday hours and dominated the period after the pm peak and the next am peak period. They were at their lowest level during the highest peak of the day (am peak). Speed-related crashes dominated weekends.

Speed-related crash rates (in crashes per million vehicle miles traveled) peaked during the late evening and early morning hours, between 11 pm and 4 am on weekdays, and between 10 pm and 7 am on weekends.

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[6] That is, traffic speeds were found to have remained unchanged for drivers who had not seen the sign activated when their speeds were recorded.

[7] Why estimate is conservative: Semi-trucks crossing the detector location faster in the after period, would have arrived at the PC at higher speeds. In that case, detected speed reduction at the PC in the after period would have been smaller, not larger—sign effectiveness would have been underestimated.

FINDINGS

Very small percentages of drivers passing the detectors, 860 feet upstream from the curve PC drove at or below the speed limit of 50 mph: 18% during weekdays and 5% during weekends. Average **non-violator** speeds at this location were 58.0 mph for small vehicles, and 54.6 mph for all large vehicles. Speeds at the North Avenue curve PC were also relatively high, given that the curve design speed was 50 mph, but average **non-violator** speeds were 57.8 mph for small vehicles, 53.4 mph for single-unit trucks, and 52.9 mph for semi-trucks (non-violators represented 98.2% of the traffic).

Speed-related crashes represented two-thirds of all crashes at the study site; large vehicles, were involved in 16% of these crashes. Thus large vehicles were overinvolved since their presence in the traffic stream was 7% on weekdays and 3% on weekends (5.86% overall). Crash rates for speed-related crashes were three times higher for large vehicles than small vehicles. Crash rates for speed-related crashes peaked during the hours when violation rates (violations/1,000 veh) also peaked, that is, during the late evening and early morning hours.

Sign threshold settings were such, that 28% of semi-truck drivers, and 0.6% of small vehicle drivers activated the sign. Among the 584,512 vehicles analyzed for this report, there were 5,832 semi-truck and 3,532 small vehicle violators, out of a total of 10,415 violators (1.8% of all vehicles). The numbers of violations peaked during daylight hours at 78 violations per hour. The majority of hourly violations was large vehicle-related during weekdays; small vehicle violations were the majority during weekends.

Hourly volume peaking characteristics were different during weekdays and weekends. Average speeds (measured 860 feet before the study curve) dropped by 8-10 mph during weekday peak periods. Violator average speeds, however, demonstrated very small fluctuations during the hours of the day, and did not change throughout the week.

Ample statistical information was available to document that background speeds of all analyzed vehicle types remained practically unchanged in the period following sign unveiling: no speed change was evident at the detectors; speeds of drivers who did not trigger the sign remained unchanged at the PC. Thus, violator speed reductions at the PC in the after period could be attributed to sign operation— they were not due to a general background speed reduction at the study site.

Speed reduction for semi-truck violators at the PC in the after period was 3.2 mph. Large sample sizes supported this finding, which was statistically significant at the 0.05 level of significance, with a 95% confidence interval between 2.5 and 3.9 mph.

Violator speed reduction findings for small vehicles (passenger cars, vans, pickup trucks and SUVs) and single-unit trucks and buses were **tentative** because they were based on very small violator sample sizes for the before period. Violators among small vehicles reduced their curve entering speeds by an average of 6.4 mph (95% confidence interval 2.8 to 10.0 mph); those among single-unit trucks and buses reduced their speeds by 5.1 mph (95% confidence interval 0.1 to 10.1 mph).

DISCUSSION

The following discussion addresses the issue of setting reasonable sign activation threshold values, in light of the information that was gathered and analyzed during this evaluation.

The best-established violator information at the PC was that for semi-trucks (these violators represented 2% of all traffic). Semi-truck violator speeds at the PC were excessive, at 56.8 mph, during the before period. After sign activation they were brought in-line with non-violator speeds, dropping to 53.6 mph. It is possible that violator speeds could drop further if the sign speed threshold was lowered; however, if they did, violators would, at some point, be entering the PC at lower speeds than non-violators. Given that 27.7% of all semi truck drivers activated the sign, it is reasonable to assume that the semi-truck drivers most likely to be involved in speed-related crashes have already been targeted.

One issue that was identified in the course of the evaluation was with the use of a single combination speed-and-gross vehicle weight (GVW) threshold for a given vehicle class (**Table C2**). Such a threshold would not trigger the sign for lighter speeding vehicles within that vehicle class, which is not a desirable situation. Evidence of this problem can be found in the maximum non-violator semi-truck speed recorded at the detectors, shown in **Table C8**: a maximum speed of 68.6 mph was recorded in the after period; sign threshold speed was 58 mph for semi-trucks. The semi-truck who crossed the detectors at the maximum recorded speed did not meet the GVW threshold and did not activate the sign, although it exceeded the speed threshold for its class.

Ideally, two separate thresholds should be used within each vehicle class: a speed/GVW threshold for heavier vehicles and a simple speed threshold for lighter vehicles. If a single threshold must be used, it would be advisable to use the speed threshold appropriate for large vehicles without any GVW restrictions. Thus **all** speeding vehicles in that class would activate the sign.

If GVW thresholds in place during the evaluation were to be dropped, and the speed thresholds were to be used alone, an increase in the number of violators would occur. This would be due to speeding vehicles that were lighter than the GVW threshold—should the GVW threshold be dropped, they would start activating the sign.

Given the sign threshold settings in place during the evaluation, the number of violations peaked at 78 per hour; the middle lane accounted for approximately 40 of these violations on a typical weekday. Thus the sign was activated between every 46 to 90 seconds.[8] Given that the sign remained activated for five seconds, drivers were exposed to the sign message between approximately 200 and 400 seconds during a peak violation hour (5.6 to 11.1% of the time). Thus, the number of activations was such that drivers

[8] 90 seconds, if activations in other lanes were simultaneous with middle lane activations.

were not overexposed to sign activations. The number of activations could be increased (e.g., by lowering speed threshold values and/or dropping the GVW restrictions), if this was deemed desirable. Historical vehicle class, speed and weight data obtained through system detectors could be used to obtain a precise estimate of the number of activations that would result from any change in sign threshold values.

CONCLUSIONS

Two-thirds of all crashes at the study site were speed-related. Large vehicles were involved in such crashes in disproportionate numbers to their presence in the traffic stream (16% of the crashes, 5.9% presence in the traffic stream). Their crash rates in speed-related crashes were three times the rates of small vehicles at the study site. Thus, targeting speeding large vehicle drivers was important for the evaluated sign.

The sign was activated by 1.8% of the drivers (violators), under sign speed and gross vehicle weight (GVW) threshold values in place during the evaluation period. Average speed decreases were observed among those drivers as they entered the North Avenue curve point of curvature (PC) in the period following sign unveiling. Large numbers of observations were available to establish that background speeds at the study site remained unchanged throughout the evaluation period, thus the speed reductions observed for violators were due to the sign, not general speed trends at the evaluated site.

The best established sign-related speed reduction findings were for semi-truck violators whose speeds were reduced by 3.2 mph at the PC as a result of sign operation. This speed reduction was statistically significant at the 0.05 level of significance with a 95% confidence interval between 2.5 and 3.9 mph. Semi-truck violations represented 56% of all violations; 28% of all semi-trucks in the traffic stream activated the sign. Violators entered the PC at 56.8 mph before the sign was unveiled, which was 3.8 mph faster than non-violators. They were driving 0.3 mph faster than non-violators after the sign was operational.

Violator speed reductions were identified for small vehicles and single-unit trucks and buses; however, these findings were based on very small violator sample sizes and should be viewed as tentative only.

Hourly crash rates for speed-related crashes correlated well with hourly violation rates (violations per thousand vehicles). Thus, the evaluated sign targeted a larger percentage of the drivers most likely to be involved in speed-related crashes. Given its demonstrated effectiveness in reducing speeds at the curve, a drop in speed-related crashes, would be a reasonable expectation.

Small, but consistent speed differences were identified between individual lanes (median lane fastest, shoulder lane slowest—findings not reported here). The choice of individual sign displays for each lane was, thus, very appropriate.

RECOMMENDATIONS

Short-term:

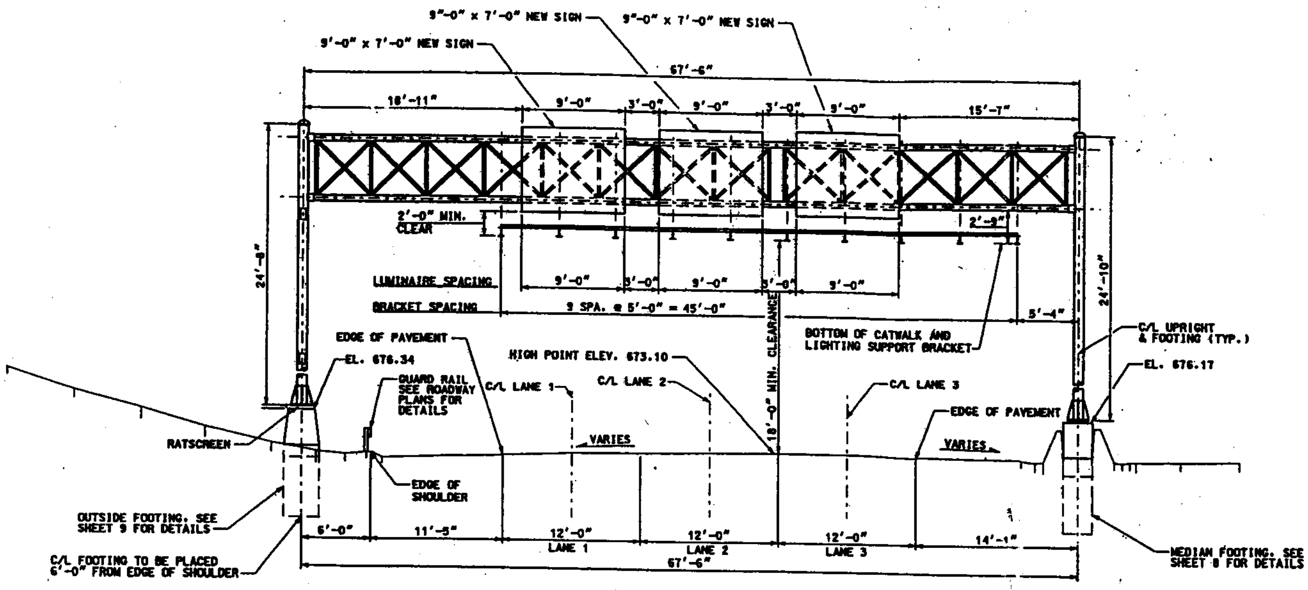
1. It would be desirable to modify the current sign threshold criteria so that all speeding vehicles will activate the sign, regardless of vehicle weight. This objective could be accomplished by removing the GVW threshold and relying solely on vehicle class and vehicle speed to trigger the sign.
2. It would be desirable to eliminate cases when the sign CPU places vehicles in the wrong vehicle class.
3. It would be desirable to reduce the number of vehicle classes currently detected, from 15 to four or five. The presence of too many classes complicates the task of monitoring proper sign operation.

Long-term:

1. It would be desirable to revisit the crash analysis after a few years, when substantial crash experience will have been accumulated, in order to perform a before-after analysis of speed-related crash statistics.
2. It would be desirable to collect violator and non-violator speed data when the study location is revisited, in order to address long-term sign effectiveness.
3. It would be desirable to be able to adjust speed thresholds based on weather and pavement conditions (for example, lower speed thresholds for wet pavement, or when fog is present).
4. It would be desirable to apply separate speed thresholds, depending on the time of day: lower speed thresholds may be more appropriate during peak traffic hours of the day, when slow or stopped traffic may be present downstream from the study curve.

APPENDIX A
SIGN BRIDGE DRAWINGS & STUDY SITE AERIAL PHOTOS

Figure A1. Sign Bridge Dimension Details.



ELEVATION

STRUCTURE S-40-424, STA. 1129+00
(LOOKING NORTH ON SOUTH BOUND)

GENERAL NOTES

DRAWINGS SHALL NOT BE SCALED

CONTRACTOR SHALL VERIFY DIMENSIONS BEFORE FABRICATION OF TOWERS.

MAINTAIN 2'-0" MIN. CLEARANCE FROM BOTTOM OF CATWALK. CENTER SIGNS ON TRUSS AND ADJUST SIGN POSITION IF REQUIRED TO MAINTAIN THIS CLEARANCE.

CATWALK CONSIDERED INCIDENTAL TO SIGN BRIDGES.

SIGN BRIDGE IDENTIFICATON PLACQUES CONSIDERED INCIDENTAL TO SIGN BRIDGES.

PROVIDE CATWALK AND LIGHTING ON ALL STRUCTURES.

ELEVATIONS ARE IN FEET UNLESS OTHERWISE SHOWN OR NOTED.

ALTERNATE DESIGNS ARE NOT ALLOWED.

(XX-X) SIGN NUMBER

DESIGN DATA

SIGN BRIDGE	DESIGN SIGN AREA *	MAX. SIGN DEPTH
S-40-424	324 S.F.	9'
S-40-224	170 S.F.	8'

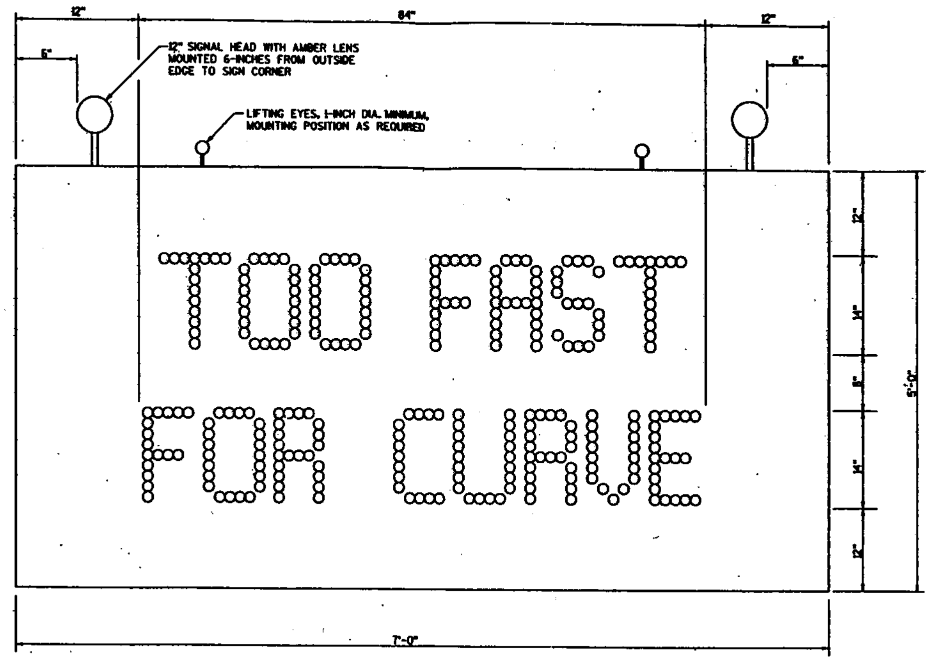
DESIGNED ACCORDING TO A.A.S.H.T.O. "STANDARD SPECIFICATION FOR STRUCTURAL SUPPORTS FOR HIGHWAY SIGNS, LUMINAIRES AND TRAFFIC SIGNALS"

WIND VELOCITY = 85 MPH

ESTIMATE OF QUANTITIES

ITEM NUMBER	BID ITEM	UNIT	S-40-424	S-40-224	TOTAL
63601	CONCRETE MASONARY, SIGN SUPPORTS	CY	19	9	28
63610	HIGH STRENGTH BAR STEEL REINFORCEMENT, SIGN SUPPORTS	LB	1390	630	2020
63821	MOVING SIGN, TYPE 1	EA.		1	1
64166	SIGN BRIDGE STRUCTURE, S-40-424	LS	1		1
90004PP	RELOCATING SIGN BRIDGE, STRUCTURE S-40-224	LS		1	1

Figure A2. Sign Face Dimension Details.



NOTES:

1. MAXIMUM SIGN WEIGHT NOT TO EXCEED 650 LBS.
2. SEE SIGN STRUCTURE PLANS S-40-424 FOR LAYOUT CONFIGURATION, MOUNTING REQUIREMENTS, AND ADDITIONAL INFORMATION

Figure A3. Approach to Study Site.

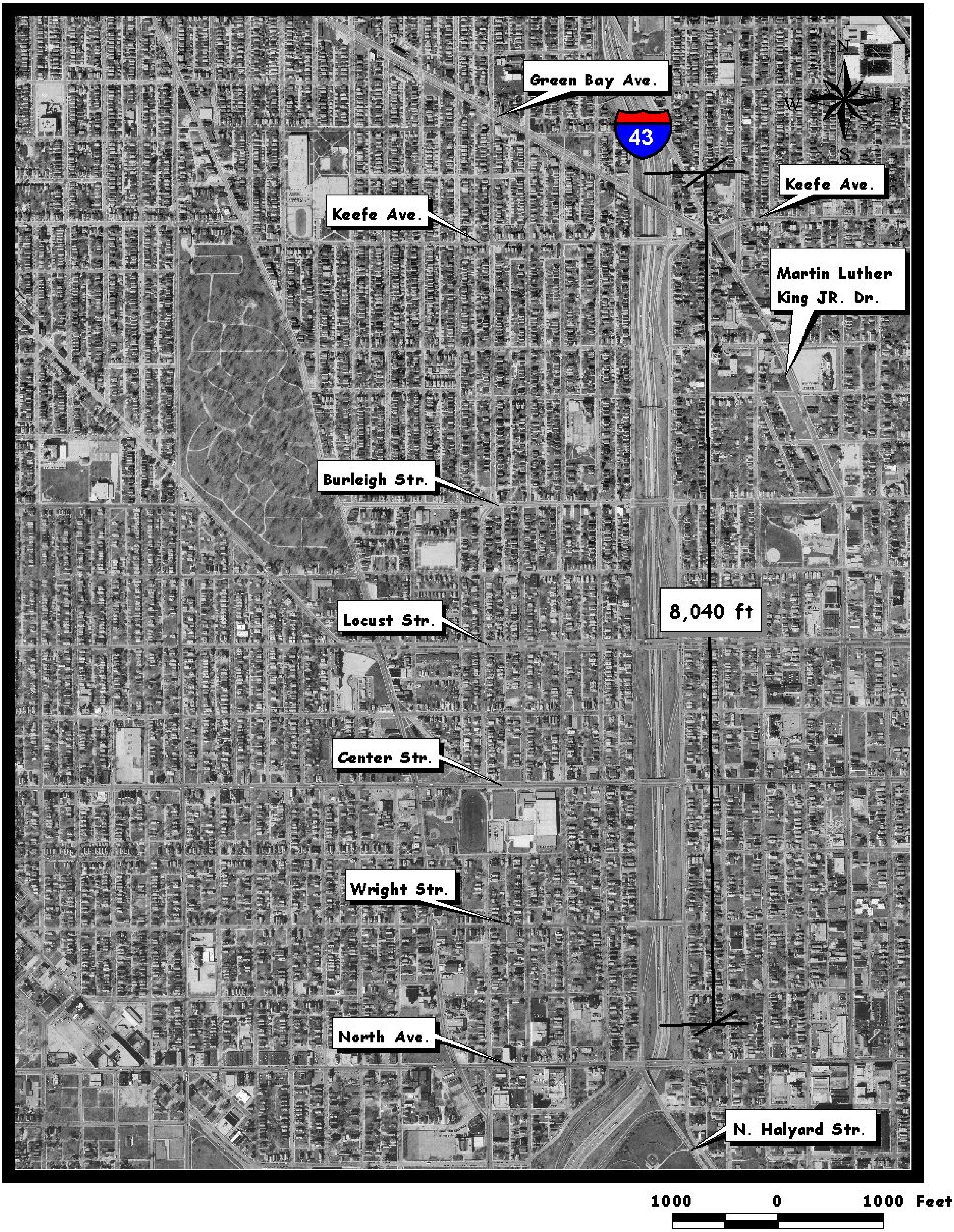


Figure A4. Signs in the Vicinity of the Study Site.

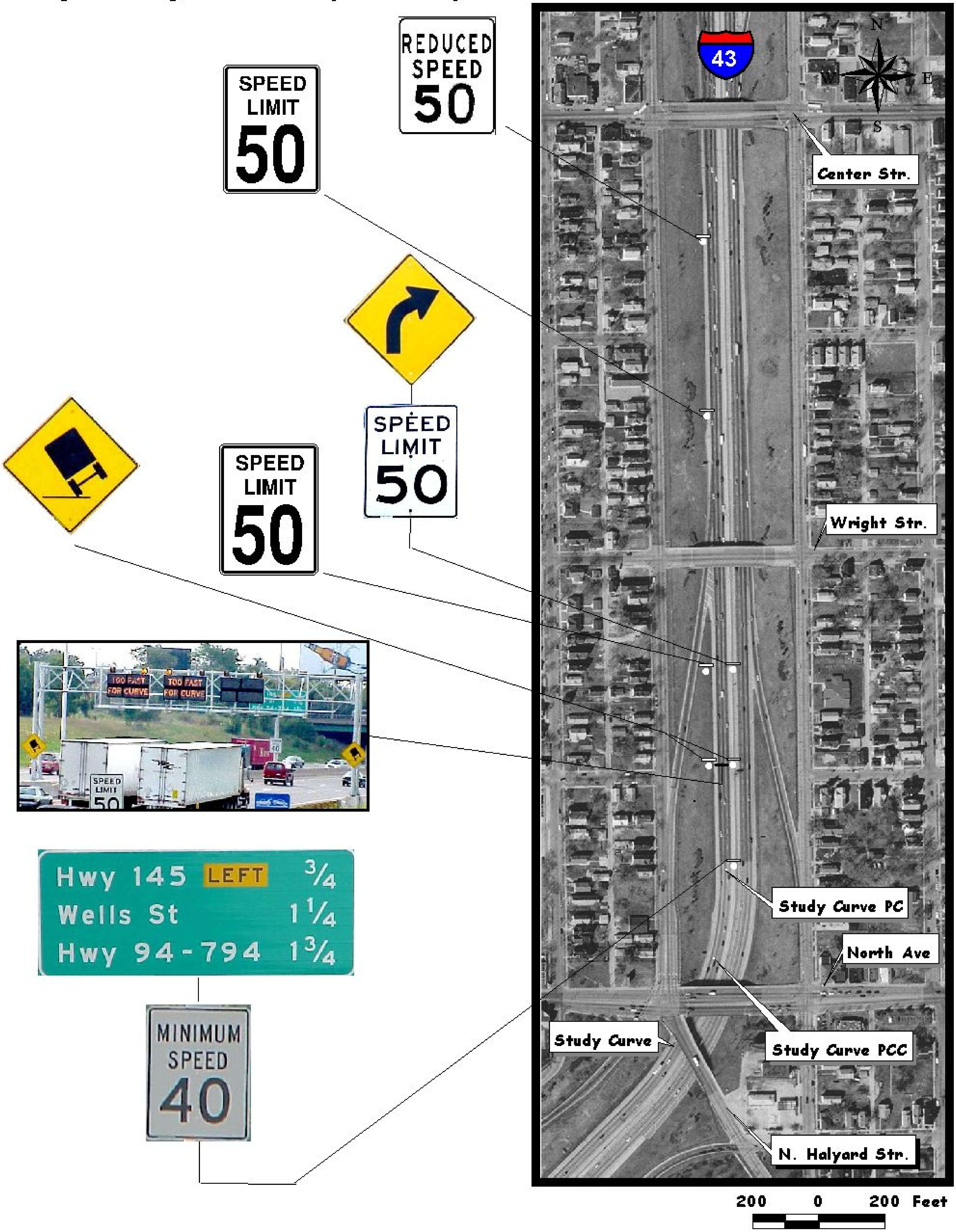
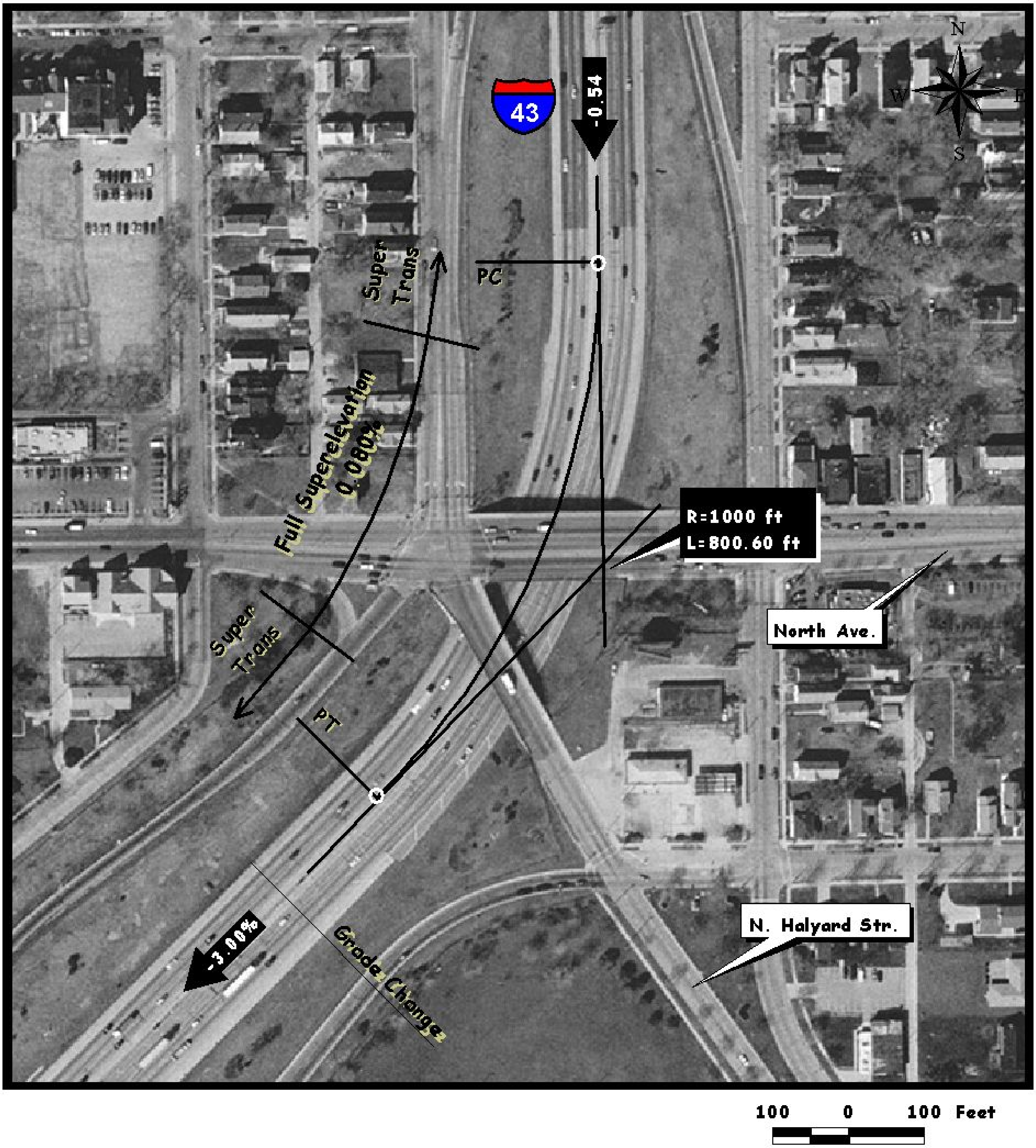


Figure A5. Curve Geometry Details.



APPENDIX B
GENERAL TRAFFIC AND VIOLATOR CHARACTERISTICS

INTRODUCTION

This Appendix presents 24-hour speed conditions at the detector location during the ten days that data was gathered at the PC using a laser gun (see **Table C1** for a listing of the hours during which data at the PC was collected). Analyzed information was gathered through the evaluated sign hardware (pavement-embedded detectors located 860 feet before the curve PC), capable of identifying speed and vehicle class for each vehicle entering the study site, which has a posted speed limit of 50 mph. **Table B1** below presents the vehicle classification scheme loaded on the system CPU.

Table B1. Vehicle Classification Definitions used by Automatic Data Recorder.

ADR Default Scheme F Classification Definitions (v429)	
2 axle vehicles. Default class = 2 Class 5: Axle Spacing: 13 Feet to 20 Feet Class 4: Axle Spacing: 20 Feet to 40 Feet Class 3: Axle Spacing: 10.2 Feet to 13 Feet Class 2: Axle Spacing: 6 Feet to 10.2 Feet Class 1: Axle Spacing: 0 Feet to 6 Feet **3 axle vehicles. Default class = 2** Class 8: Axle Spacing: 6 Feet to 17 Feet, 14 Feet to 40 Feet Class 6: Axle Spacing: 6 Feet to 23 Feet, 0 Feet to 6 Feet Class 4: Axle Spacing: 20 Feet to 40 Feet, 0 Feet to 6 Feet Class 3: Axle Spacing: 10.2 Feet to 13 Feet, 6 Feet to 18 Feet Class 2: Axle Spacing: 6 Feet to 10.2 Feet, 6 Feet to 18 Feet **4 axle vehicles. Default class = 2** Class 8: Axle Spacing: 6 Feet to 20 Feet, 0 Feet to 6 Feet, 6 Feet to 40 Feet Class 8: Axle Spacing: 6 Feet to 17 Feet, 14 Feet to 40 Feet, 0 Feet to 6 Feet Class 7: Axle Spacing: 6 Feet to 23 Feet, 0 Feet to 9 Feet, 0 Feet to 9 Feet Class 3: Axle Spacing: 10.2 Feet to 13 Feet, 6 Feet to 18 Feet, 0 Feet to 6 Feet Class 2: Axle Spacing: 6 Feet to 10.2 Feet, 6 Feet to 18 Feet, 0 Feet to 6 Feet	**5 axle vehicles. Default class = 9** Class 11: Axle Spacing: 6 Feet to 17 Feet, 11 Feet to 25 Feet, 6 Feet to 18 Feet, 11 Feet to 25 Feet Class 9: Axle Spacing: 6 Feet to 22 Feet, 0 Feet to 6 Feet, 6 Feet to 23 Feet, 0 Feet to 23 Feet Class 9: Axle Spacing: 6 Feet to 22 Feet, 0 Feet to 6 Feet, 6 Feet to 40 Feet, 0 Feet to 14 Feet **6 axle vehicles. Default class = 10** Class 12: Axle Spacing: 6 Feet to 22 Feet, 0 Feet to 6 Feet, 0 Feet to 25 Feet, 6 Feet to 18 Feet, 11 Feet to 25 Feet Class 10: Axle Spacing: 6 Feet to 22 Feet, 0 Feet to 6 Feet, 0 Feet to 40 Feet, 0 Feet to 11 Feet, 0 Feet to 11 Feet **7 axle vehicles. Default class = 13** Class 10: Axle Spacing: 6 Feet to 22 Feet, 0 Feet to 6 Feet, 0 Feet to 40 Feet, 0 Feet to 13 Feet, 0 Feet to 12 Feet, 0 Feet to 12 Feet **8 axle vehicles. Default class = 15** **9 axle vehicles. Default class = 15** **10 axle vehicles. Default class = 15** **11 axle vehicles. Default class = 15** **12 axle vehicles. Default class = 15** **13 axle vehicles. Default class = 15** **14 axle vehicles. Default class = 15** **15 axle vehicles. Default class = 15**

Source: Automatic Data Recorder (ADR) Plus User Manual. Peek Part Number 99-133js v429.

Vehicle class (**Table B1** definitions) presence in the traffic stream is presented in Appendix **tables**; **figure** information is summarized into four **vehicle categories** with identical or nearly identical sign speed threshold settings, for the sake of presentation economy. Vehicle classes with minimal presence in the traffic stream were omitted from figures. **Vehicle classes** contained in each **vehicle category** are shown in **Table B2**.

The Appendix establishes traffic conditions at the study site during the before and the after analysis periods, in terms of overall and violator speed characteristics, for the most prevalent vehicle classes. This information is intended to provide useful information for adjusting sign threshold criteria; also to provide background information about general traffic conditions during the hours laser gun speed data were collected at the curve PC. Only vehicles traveling at 30 mph or greater speeds are included in these statistics; lower speeds would indicate unusual conditions (e.g., a maintenance vehicle)—peak hour speeds were between 48 and 50 mph.

Because distinct traffic patterns existed at the study site during weekdays and weekends, separate statistics are presented for weekdays and weekends. Statistics for all drivers are presented first—weekday information is followed by weekend information; violator statistics follow, in the same sequence of presentation.

Table B2. Vehicle Classes Included in Each Vehicle Category.

Vehicle category	**Abbreviation**	**Vehicle classes**	**Sign Threshold Speed (MPH)**
Small vehicles	Small	2,3	70
Smaller single-unit trucks	SU Truck -	4,5	62
Larger single-unit trucks	SU Truck +	6,7	60
Semi-trucks	Semi-Truck	8,9	58 & 57, respectively

Note: The term "single-unit truck" is used for brevity. It includes buses.

Tables B3 – B5 present general vehicle classification and violation statistics, based on 24-hour periods, for all days, weekdays and weekends. Information is based on a total of 584,512 vehicles, 10,415 of which exceeded sign threshold values. These violations represented 1.8% of all vehicles. Overall, the highest number of violations (n=5,832—56% of all violations) corresponded to semi-trucks; the second highest number (n=3,532—34% of all violations) was small vehicles. These numbers represented 27.73% and 0.65% of the corresponding vehicle classes (**Table B3**).

GENERAL TRAFFIC CHARACTERISTICS

WEEKDAYS

Volumes peaked between 6 and 9 am (**Figure B1**), with directional volumes reaching 5,600 vph between 7 and 8 am. Midday volumes did not exceed 3,600 vph. The afternoon peak was between 5 and 6 pm with volumes reaching 4,250 vph. All other hours of the day had volumes below 2,800 vph; volumes did not exceed 600 vph during the early morning hours.

The most ***prevalent vehicle categories--*** 93% of the traffic, were class 2 and 3 vehicles. The next most common were classes 8 and 9 (shorter and longer semi trucks, respectively) with a 2% presence each. Smaller single-unit trucks (classes 4 and 5) made up another 2% of the traffic. Other vehicle categories had a very small presence in the traffic stream—see **Table B4**. Truck presence was most evident between the start of the am peak and the end of the pm peak (**Figure B1**).

Figure B2 presents ***average hourly speeds*** of the most common vehicle types in the traffic stream. During midday non-peak traffic hours, small vehicle speeds, at 58 mph, were higher than truck speeds by about 2 mph. Highest speeds of the day were recorded between 5 and 6 am (60 mph for small vehicles). During am peak traffic volume hours, speeds of all vehicle categories ranged between 48 and 50 mph (a horizontal dot-and-dash line at 50 mph indicates the speed limit at the study location).

Cumulative speed distributions in **Figure B3** indicate that approximately 15% of the vehicles drove at or below the speed limit (dot-and-dash line). 85^{th} percentile speeds ranged between 58 and 61 mph, depending of vehicle category (lower speeds corresponded to larger vehicles and vice-versa).

WEEKENDS

Volumes peaked between 11 am and 7 pm (**Figure B4**), with directional volumes reaching 3,650 vph.

The most ***prevalent vehicle categories--*** 97% of the traffic were class 2 and 3 vehicles. Larger and smaller semi trucks were approximately 2% together. Smaller single-unit trucks were approximately 1% of the traffic--see **Table B5**.

Figure B5 presents ***average hourly speeds;*** small vehicle speeds ranged between 58 and 60 mph between 5 am and 8 pm. Semi-truck speeds were about 2 mph lower during these hours. Single-unit truck information, especially during low volume hours was based on very few vehicles, leading to the wide hourly speed fluctuations evident for these vehicle categories. Speeds were lower during the low-volume early morning hours both for small cars and semi-trucks.

Cumulative speed distributions in **Figure B6** indicate that approximately 2% of the vehicles drove at or below the speed limit. 85^{th} percentile speeds ranged between 58 and 64 mph, depending of vehicle category (lower speeds corresponded to larger vehicles and vice-versa).

GENERAL VIOLATOR CHARACTERISTICS

WEEKDAYS

The most ***prevalent vehicle categories*** were semi-trucks accounting for 64% of violations; small vehicles accounted for 24%, and single-unit trucks accounted for 11%. All other vehicle categories represented approximately 1% of the violations--see **Table B4**.

Per hour violations peaked between 5 am and 2 pm at approximately 75 violations per hour, with the exception of the am peak period when the number of violations dropped precipitously due to lower overall speeds (maximum of 78 violations between 5 and 6 am; also, between 10 and 11 am). The number of semi-truck violators per hour ranged between 45-55 during these hours. Semi-trucks accounted for the largest ***number of violations*** most hours of the day (**Figure B7**). Small vehicle violations averaged about 12 per hour between 9 am and midnight, with half as many between 3 and 4 pm, when overall speeds were lower; they peaked at 20 per hour between 5 and 7 am.

Violator ***average hourly speeds*** did not fluctuate by more than 3 mph for small vehicles and more than 1 mph for semi-trucks (**Figure B8**). A similar fluctuation was observed for single-unit trucks during the hours their presence was most prevalent (between 5 am and 9 pm).

Violator ***cumulative speed distributions*** in **Figure B9** indicate that 85^{th} percentile speeds for small vehicles were 75 mph; 66 mph for smaller single-unit trucks; 64 mph for larger single-unit trucks; and 61 mph for semi-trucks (sign threshold speeds for each vehicle category are listed in **Table B2**).

Violation rates (violations per thousand vehicles) peak during the early morning hours when traffic volumes are low (**Figure B13**).

WEEKENDS

The most ***prevalent vehicle categories*** were small vehicles accounting for 59% of violations; semi-trucks accounted for 36%, and single-unit trucks accounted for 5%. All other vehicle categories represented 1% of the violations--see **Table B5**.

The maximum number of violations per hour was similar to the weekday maximum (78 violations), and occurred between 3 and 5 pm. Small vehicles were responsible for the largest ***number of violators*** most hours of the day (**Figure B10**). The number of small vehicle violators peaked between 10 am and 5 pm, ranging between 42-50 violations per hour, with slightly less than 40 between noon and 2 pm. Semi-truck violations peaked between 9 am and midnight with an average of about 20 per hour.

Violator ***average hourly speeds*** (**Figure B11**) were identical to violator weekday speeds for small vehicles and semi-trucks (**Figure B8**). A few discontinuities in the lines representing single-unit truck statistics were due to the absence of these vehicle categories during these hours.

Weekend violator ***cumulative speed distributions*** in **Figure B12** indicated 85th percentile speeds of 75 mph for smaller vehicles; 66 mph for smaller and larger single-unit trucks, and 62 mph for semi-trucks.

Violation rates peak during the late night-early morning hours (**Figure B13**).

SUMMARY OF TRAFFIC CHARACTERISTICS

Hourly volumes: Weekday am peak (6-9 am) volumes reached 5,600 vph; pm peaks (5-6 pm) carried 4,150 vph, with midday volumes not exceeding 3,600 vph. Weekend peak traffic did not exceed 3,650 vph.

Traffic composition: 93% of the traffic consisted of small vehicles during weekdays with a 4% presence of semi-trucks and 2% smaller single-unit trucks. Small vehicles made up 97% of weekend traffic; the number of trucks was half the weekday number.

Speeds: weekday speeds dropped significantly during the am peak volume period; also between 2 and 6 pm. Speeds during other times of the day did not exhibit significant variation. Weekend speeds did not fluctuate much throughout daytime hours. Approximately 18% of all drivers drove at or below the speed limit during weekdays; the percentage dropped to approximately 5% during weekends.

SUMMARY OF VIOLATOR CHARACTERISTICS

Most violations during weekdays (64%) were semi-truck-related; one quarter (24%) was small-vehicle-related. This was reversed on weekends when 59% of violations were small-vehicle-related, and 36% were semi-truck-related.

Weekday and weekend hourly violations peaked at 78 violations per hour. Weekdays were dominated by semi-trucks, which peaked at approximately 55 violations per hour. Small vehicle violations did not exceed 20 per hour. This was reversed on weekends, which were dominated by small vehicles peaking at 50 violations per hour, with semi-truck violations peaking at 20 per hour.

Average weekday and weekend speeds were identical; this was true both for small vehicles and semi-trucks. Speeds did not vary by more than 1 mph for small cars, and more than 3 mph for all types of trucks throughout daytime hours. Cumulative speed distributions were identical between weekdays and weekends both for small vehicles and for semi-trucks.

Violation rates (in violations per thousand vehicles) peak during the early morning hours, and are higher during weekdays (maximum 80 compared to a maximum of 50 on weekends).

Table B3. All Days.

Table Total

		Drivers						Table Total		
		Violators			Non-Viol					
		Row %	Col %	Count	Row %	Col %	Count	Row %	Col %	Count
Vehicle class	1 Moto	2.9%	.4%	40	97.1%	.2%	1341	100.0%	.2%	1381
	2 Auto	.7%	31.4%	3268	99.3%	85.5%	490968	100.0%	84.6%	494236
	3 Lrg Pickup Truck	.5%	2.5%	264	99.5%	9.2%	52609	100.0%	9.0%	52873
	4 Medium SU Truck	3.5%	1.6%	166	96.5%	.8%	4574	100.0%	.8%	4740
	5 Small SU Truck	6.3%	4.0%	418	93.7%	1.1%	6240	100.0%	1.1%	6658
	6 Lrg SU Truck	10.2%	3.2%	333	89.8%	.5%	2946	100.0%	.6%	3279
	7 Xtra Lrg SU Truck	2.8%	.0%	4	97.2%	.0%	141	100.0%	.0%	145
	8 Small Semi	24.1%	24.7%	2576	75.9%	1.4%	8123	100.0%	1.8%	10699
	9 Lrg Semi	31.5%	31.3%	3256	68.5%	1.2%	7072	100.0%	1.8%	10328
	10 Xtra Lrg Comb	28.3%	.1%	15	71.7%	.0%	38	100.0%	.0%	53
	11 XXtra Lrg Comb	64.7%	.6%	66	35.3%	.0%	36	100.0%	.0%	102
	12 Double-Bottom	50.0%	.1%	9	50.0%	.0%	9	100.0%	.0%	18
Table Total		1.8%	100.0%	10415	98.2%	100.0%	574097	100.0%	100.0%	584512

Table B4. Weekdays.

Part of the Week Weekday

		Drivers						Table Total		
		Violators			Non-Viol					
		Row %	Col %	Count	Row %	Col %	Count	Row %	Col %	Count
Vehicle class	1 Moto	2.7%	.3%	24	97.3%	.2%	876	100.0%	.2%	900
	2 Auto	.4%	21.6%	1591	99.6%	84.2%	364596	100.0%	83.1%	366187
	3 Lrg Pickup Truck	.4%	2.1%	153	99.6%	9.6%	41524	100.0%	9.5%	41677
	4 Medium SU Truck	3.2%	1.9%	141	96.8%	1.0%	4216	100.0%	1.0%	4357
	5 Small SU Truck	5.7%	4.6%	336	94.3%	1.3%	5603	100.0%	1.3%	5939
	6 Lrg SU Truck	9.7%	4.0%	297	90.3%	.6%	2778	100.0%	.7%	3075
	7 Xtra Lrg SU Truck	2.8%	.1%	4	97.2%	.0%	140	100.0%	.0%	144
	8 Small Semi	23.3%	29.0%	2136	76.7%	1.6%	7025	100.0%	2.1%	9161
	9 Lrg Semi	29.3%	35.4%	2610	70.7%	1.5%	6293	100.0%	2.0%	8903
	10 Xtra Lrg Comb	27.1%	.2%	13	72.9%	.0%	35	100.0%	.0%	48
	11 XXtra Lrg Comb	61.8%	.7%	55	38.2%	.0%	34	100.0%	.0%	89
	12 Double-Bottom	50.0%	.1%	8	50.0%	.0%	8	100.0%	.0%	16
Table Total		1.7%	100.0%	7368	98.3%	100.0%	433128	100.0%	100.0%	440496

Table B5. Weekends.

Part of the Week Weekend

		Drivers						Table Total		
		Violators			Non-Viol					
		Row %	Col %	Count	Row %	Col %	Count	Row %	Col %	Count
Vehicle class	1 Moto	3.3%	.5%	16	96.7%	.3%	465	100.0%	.3%	481
	2 Auto	1.3%	55.0%	1677	98.7%	89.6%	126372	100.0%	88.9%	128049
	3 Lrg Pickup Truck	1.0%	3.6%	111	99.0%	7.9%	11085	100.0%	7.8%	11196
	4 Medium SU Truck	6.5%	.8%	25	93.5%	.3%	358	100.0%	.3%	383
	5 Small SU Truck	11.4%	2.7%	82	88.6%	.5%	637	100.0%	.5%	719
	6 Lrg SU Truck	17.6%	1.2%	36	82.4%	.1%	168	100.0%	.1%	204
	7 Xtra Lrg SU Truck				100.0%	.0%	1	100.0%	.0%	1
	8 Small Semi	28.6%	14.4%	440	71.4%	.8%	1098	100.0%	1.1%	1538
	9 Lrg Semi	45.3%	21.2%	646	54.7%	.6%	779	100.0%	1.0%	1425
	10 Xtra Lrg Comb	40.0%	.1%	2	60.0%	.0%	3	100.0%	.0%	5
	11 XXtra Lrg Comb	84.6%	.4%	11	15.4%	.0%	2	100.0%	.0%	13
	12 Double-Bottom	50.0%	.0%	1	50.0%	.0%	1	100.0%	.0%	2
Table Total		2.1%	100.0%	3047	97.9%	100.0%	140969	100.0%	100.0%	144016

Figure B1. Hourly Volume

Weekdays-All Drivers

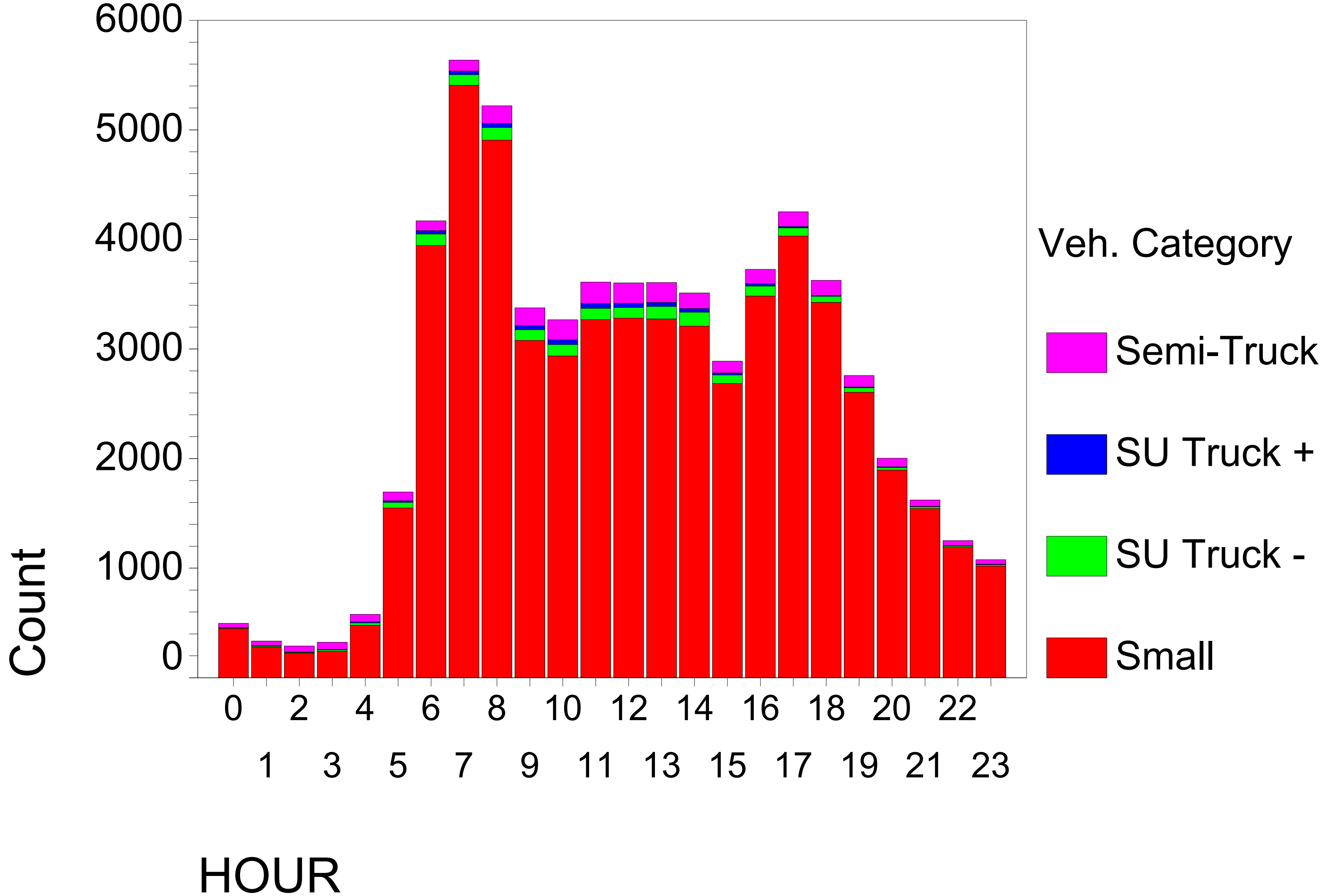


Figure B2. Average Hourly Speeds

Weekdays-All Drivers

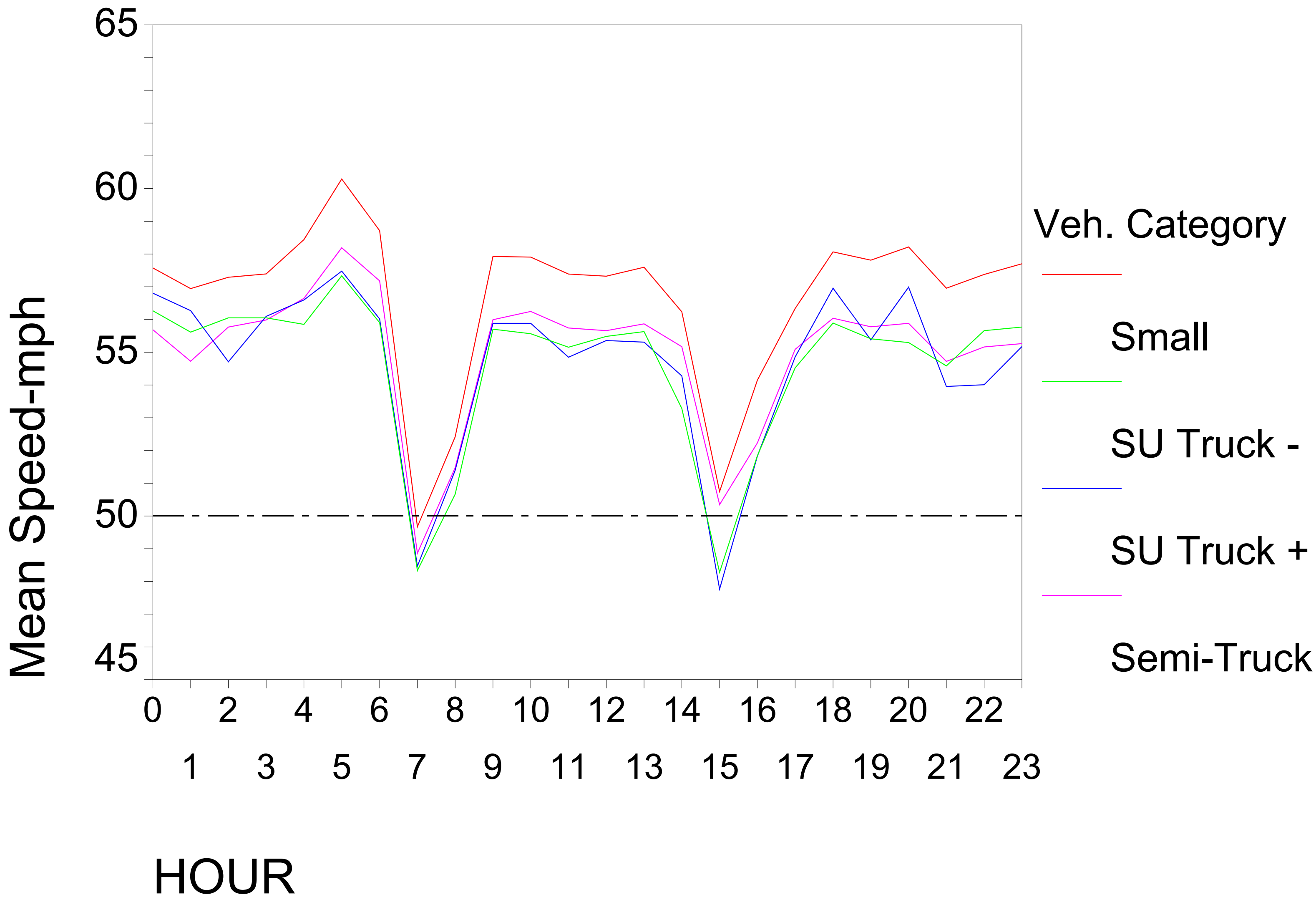


Figure B3. Cumulative Speeds

Weekdays-All Drivers

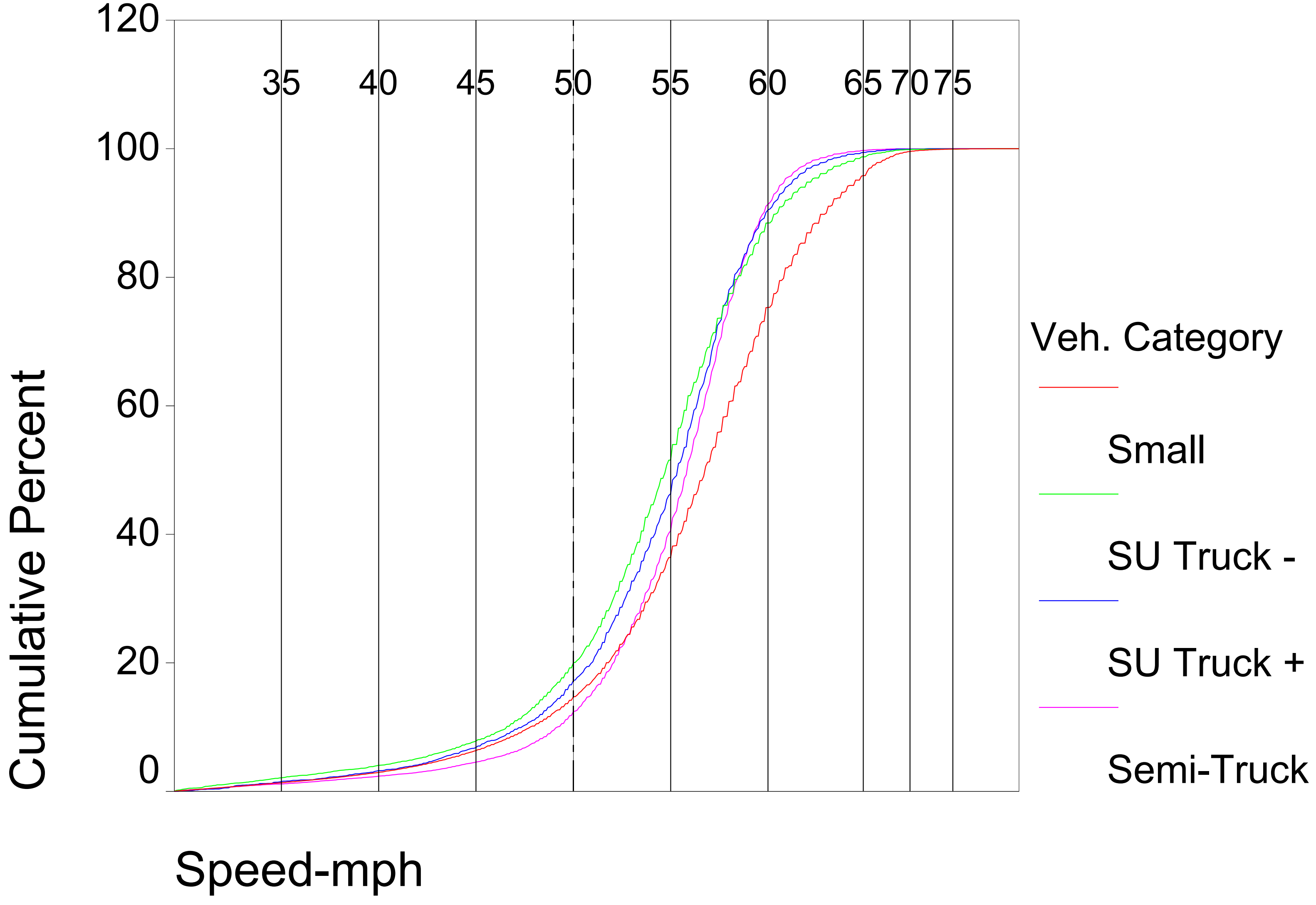


Figure B4. Hourly Volume

Weekends-All Drivers

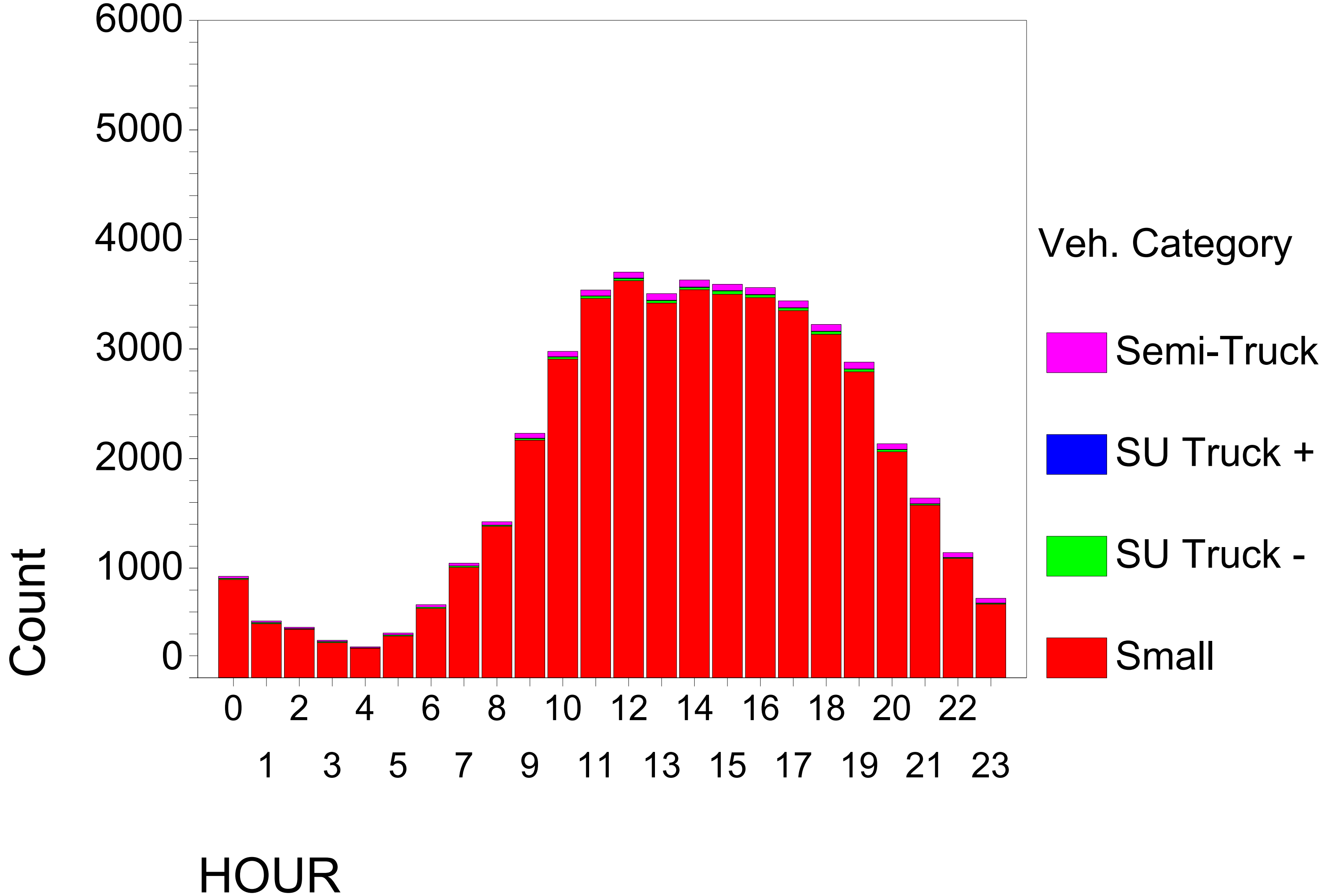


Figure B5. Average Hourly Speeds

Weekends-All Drivers

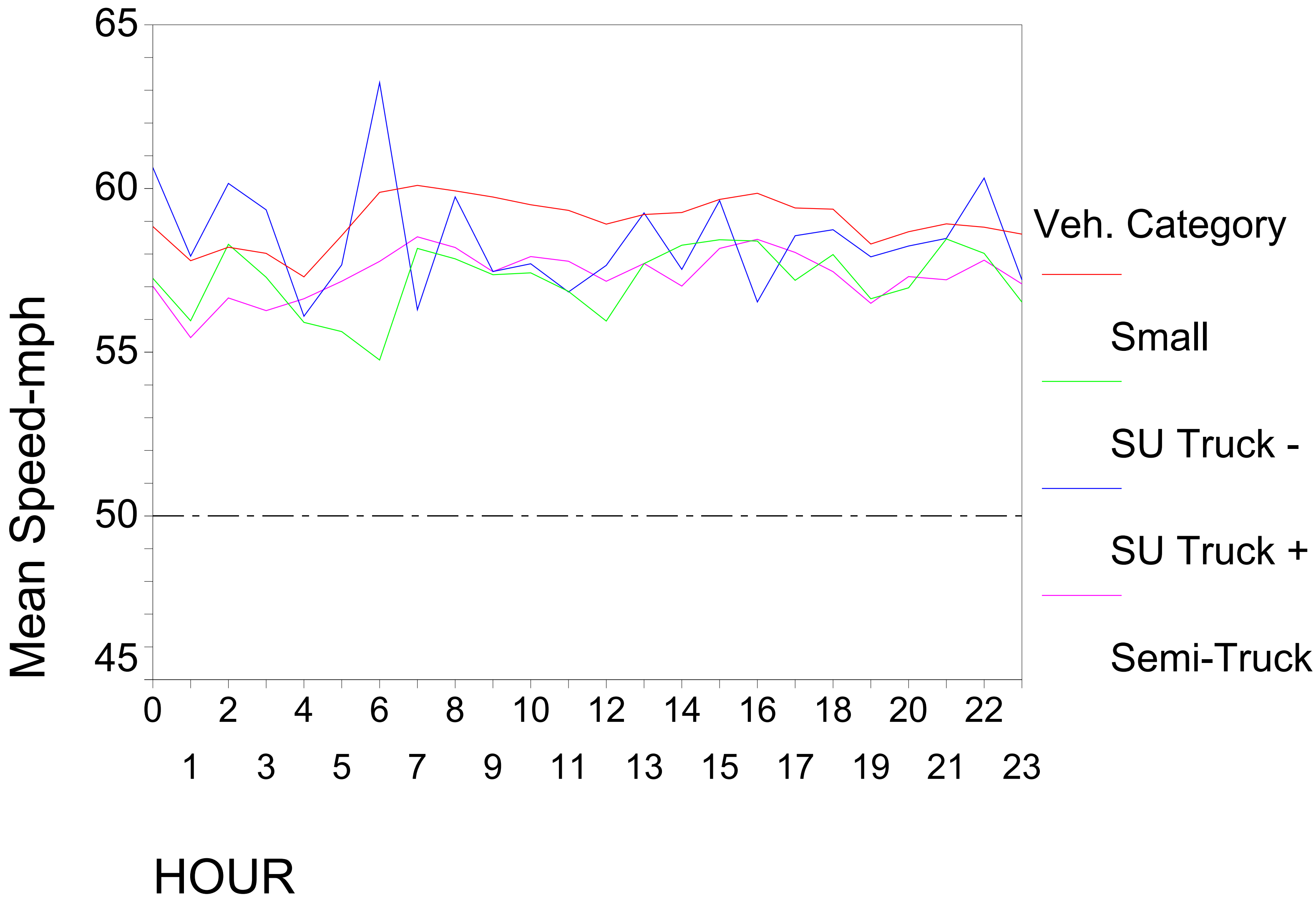


Figure B6. Cumulative Speeds

Weekends-All Drivers

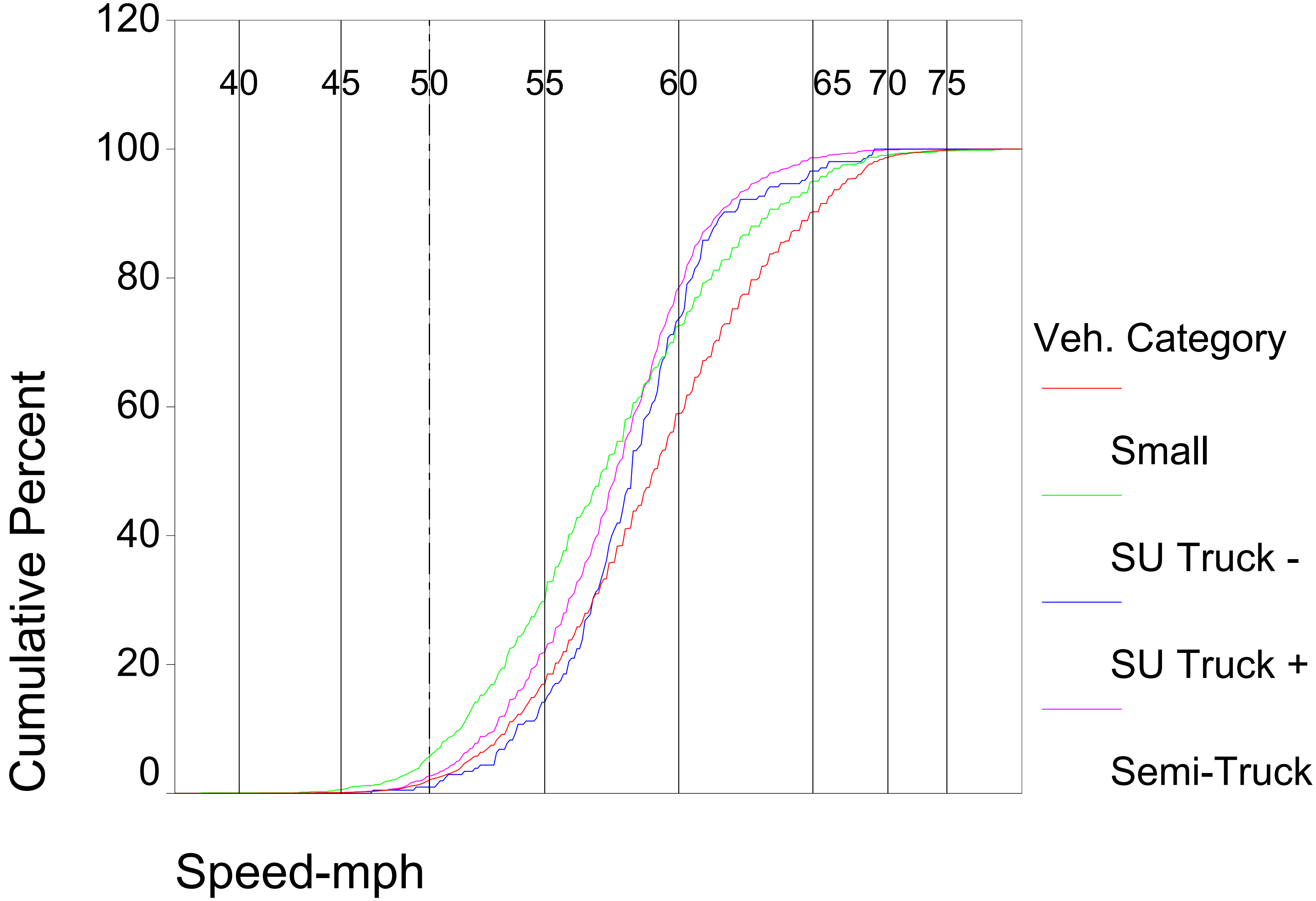
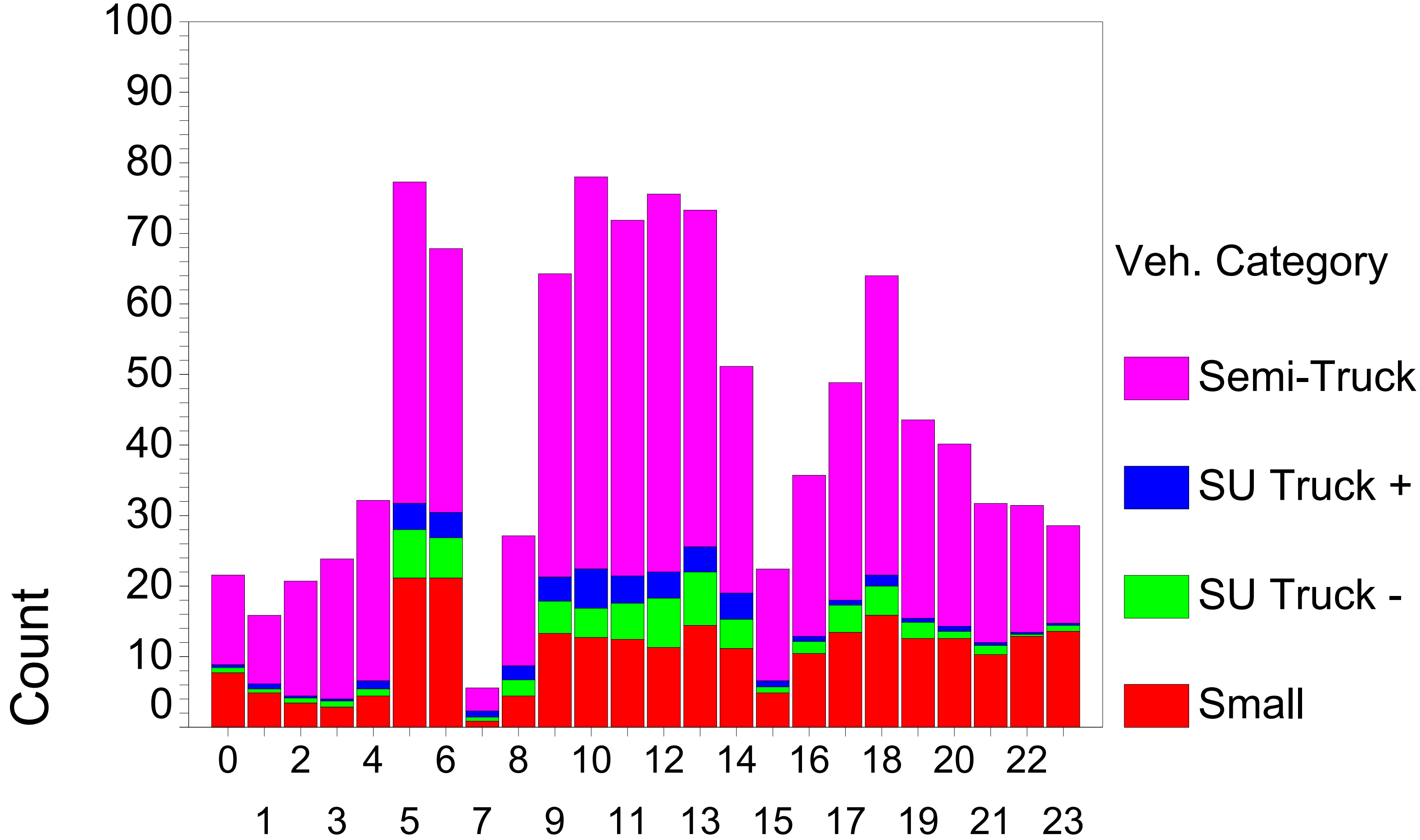


Figure B7. Violators per Hour

Weekdays



HOUR

Figure B8. Average Hourly Speeds

Weekdays-Violators

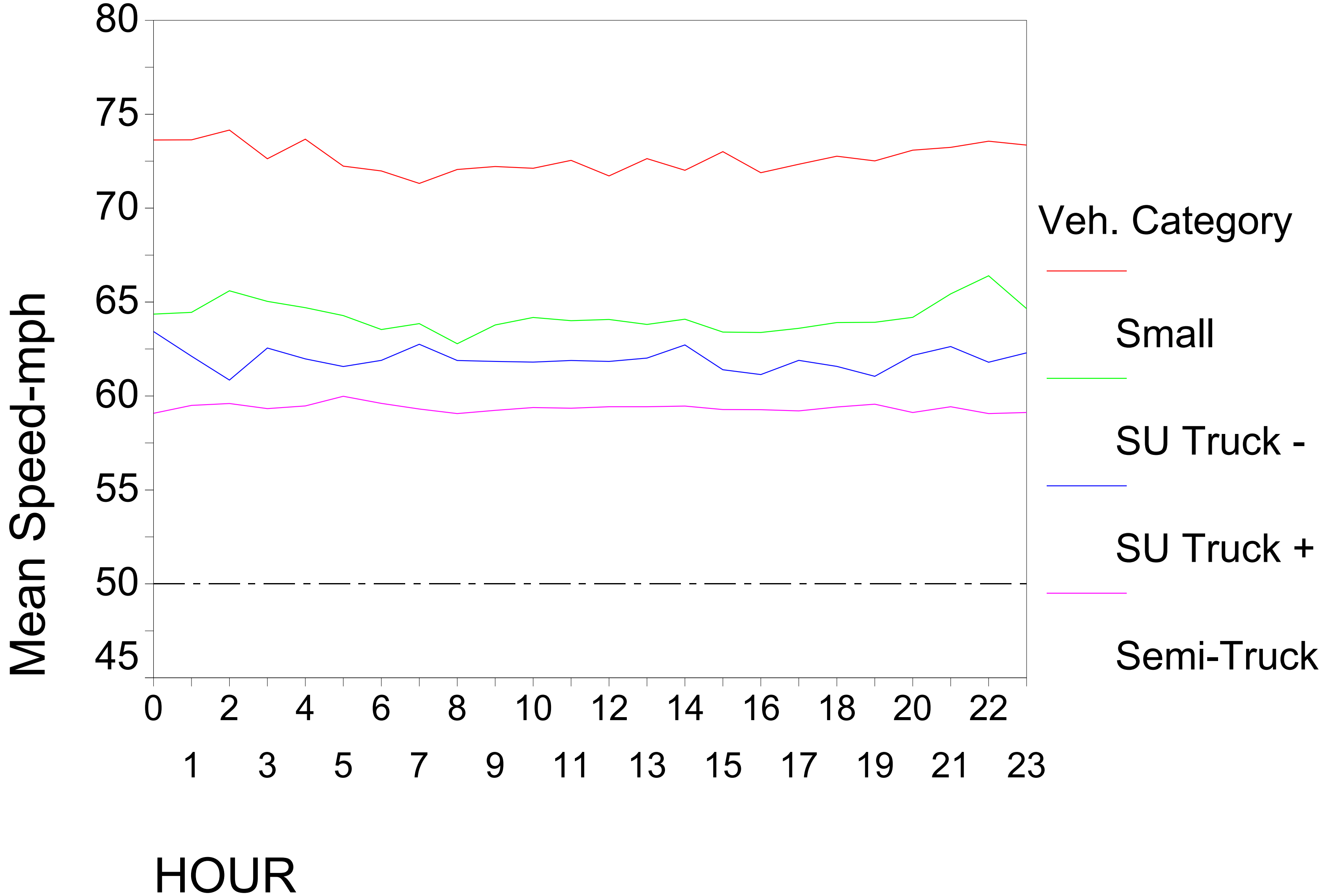


Figure B9. Cumulative Speeds

Weekdays-Violators

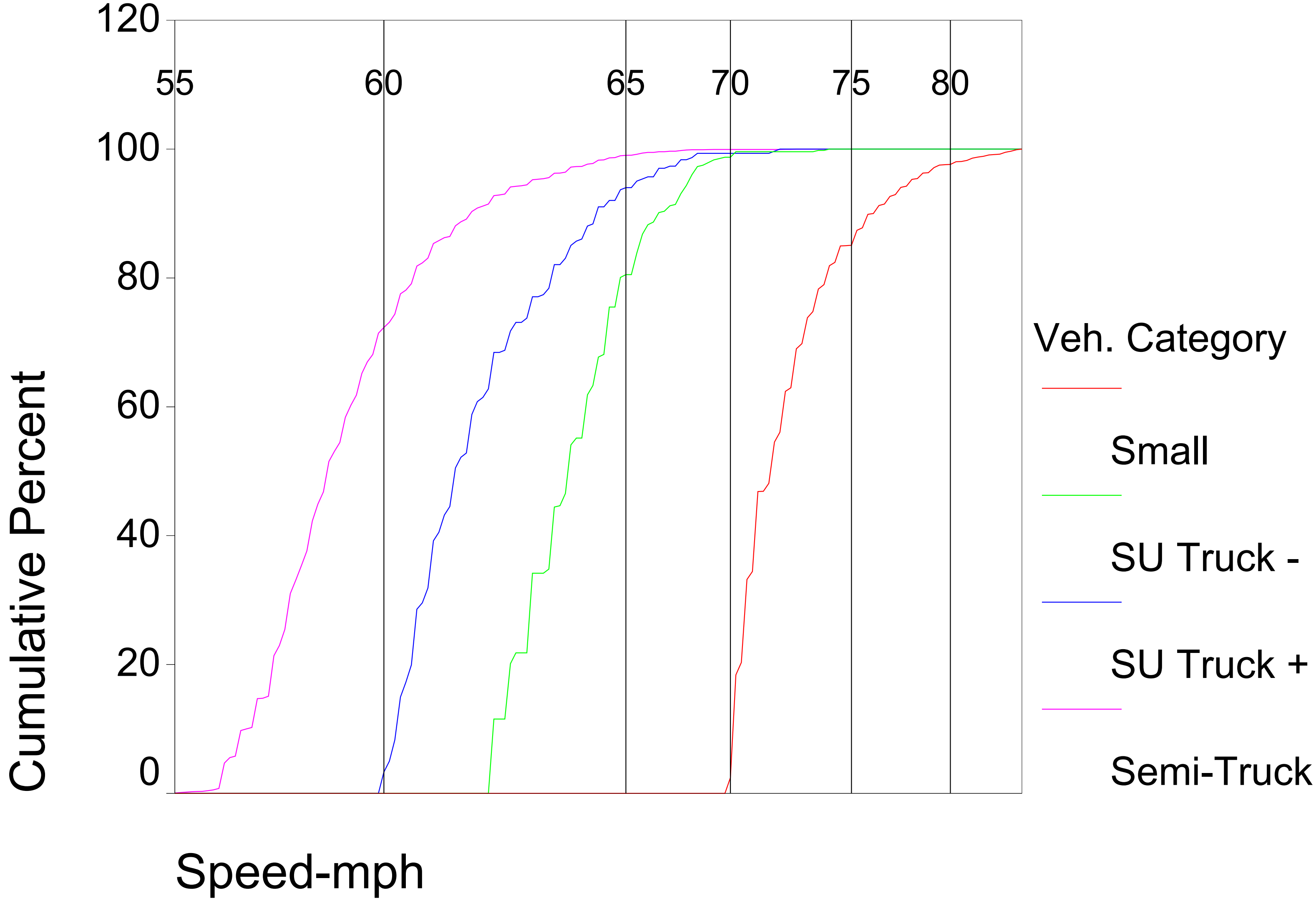


Figure B10. Violators per Hour

Weekends

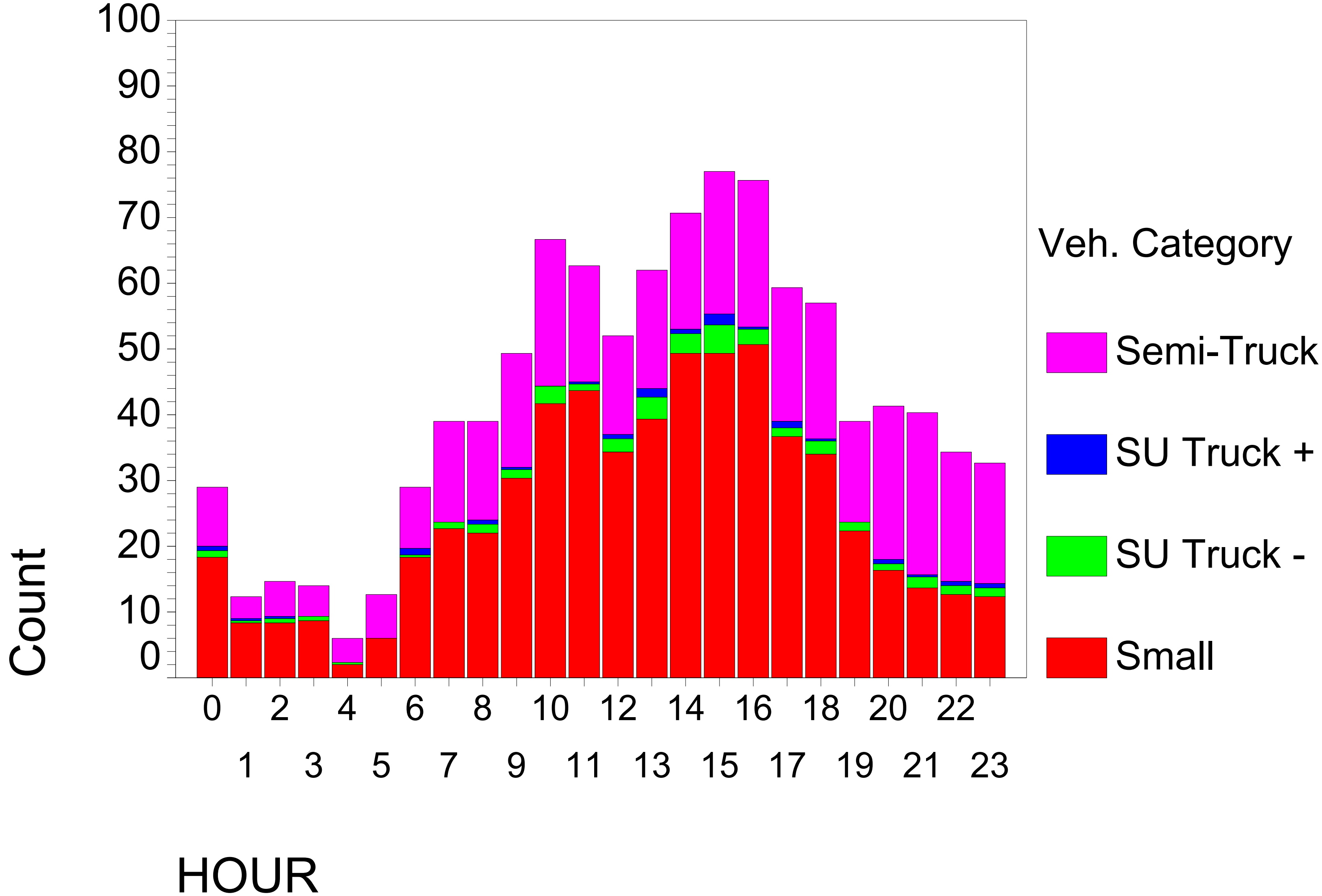


Figure B11. Average Hourly Speeds

Weekends-Violators

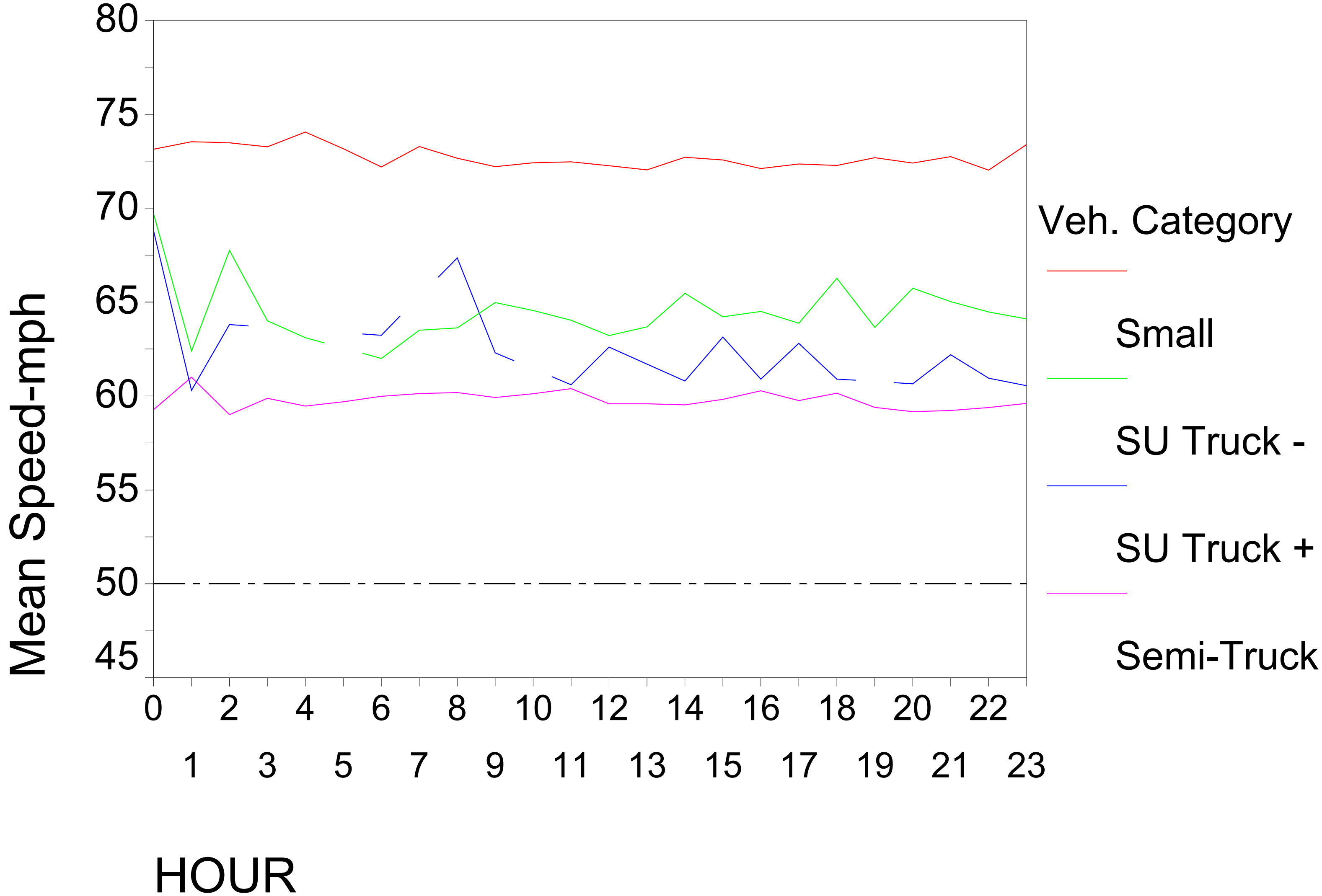


Figure B12. Cumulative Speeds

Weekends-Violators

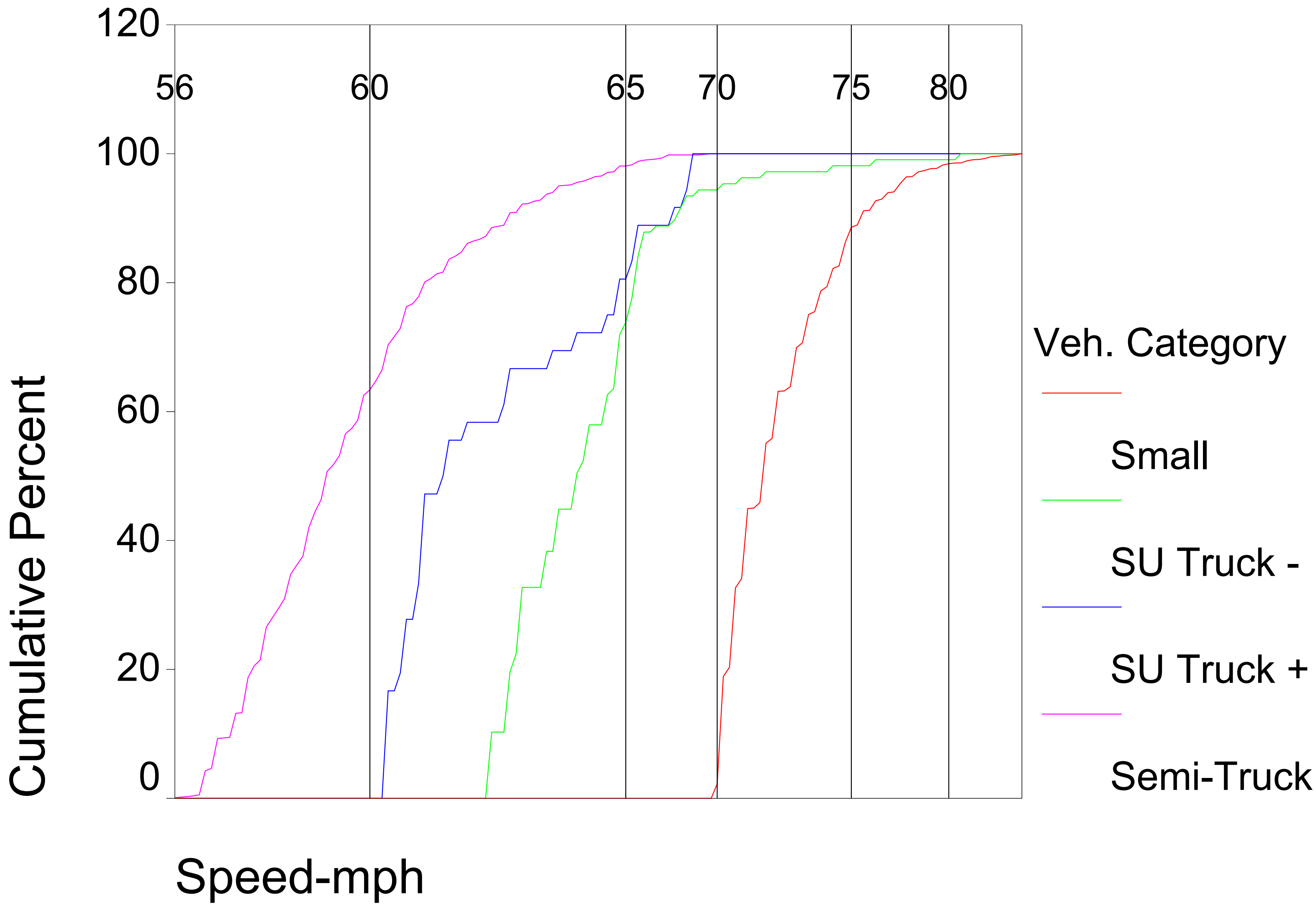


Figure B13. Hourly Violation Rates-Weekdays

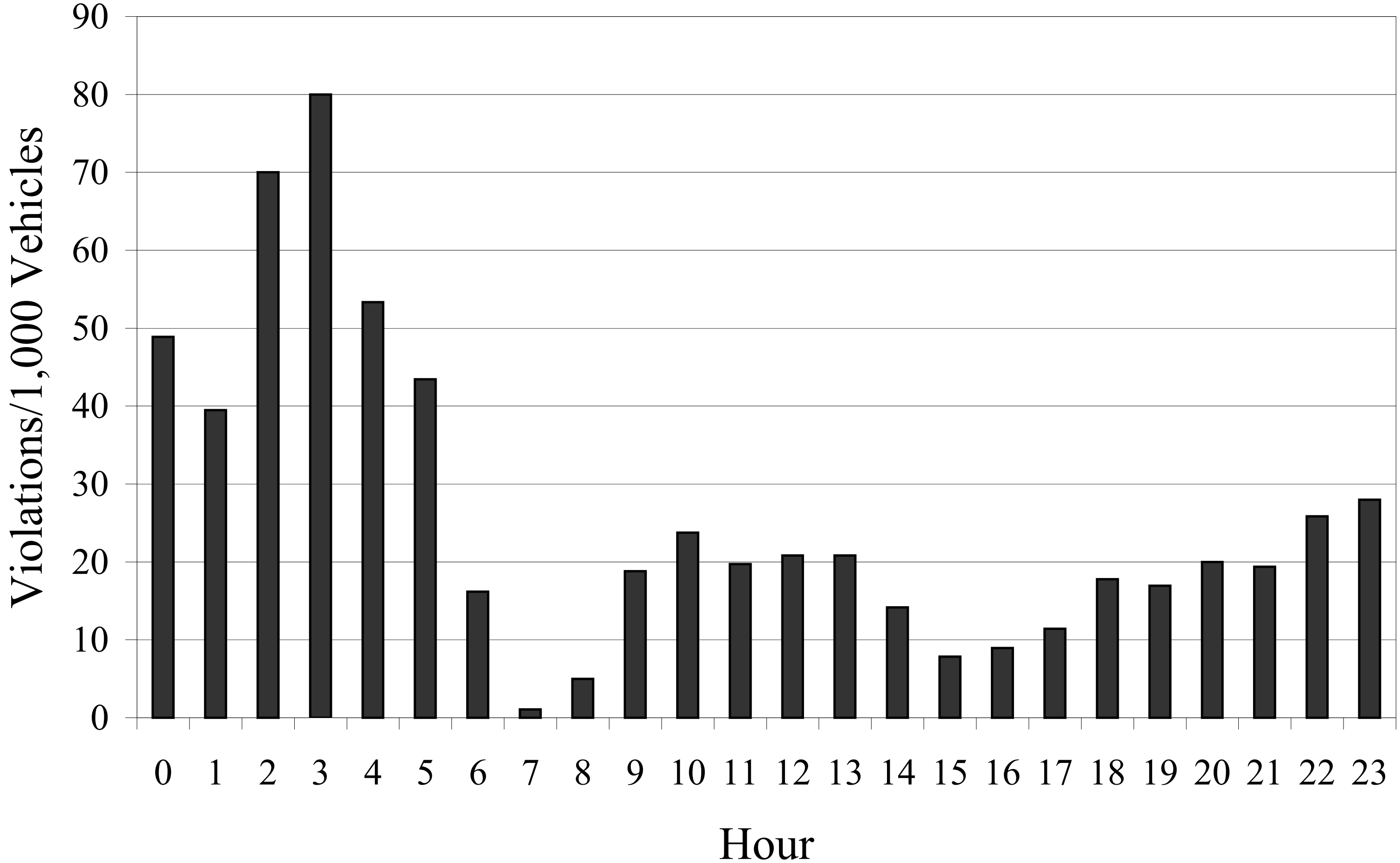
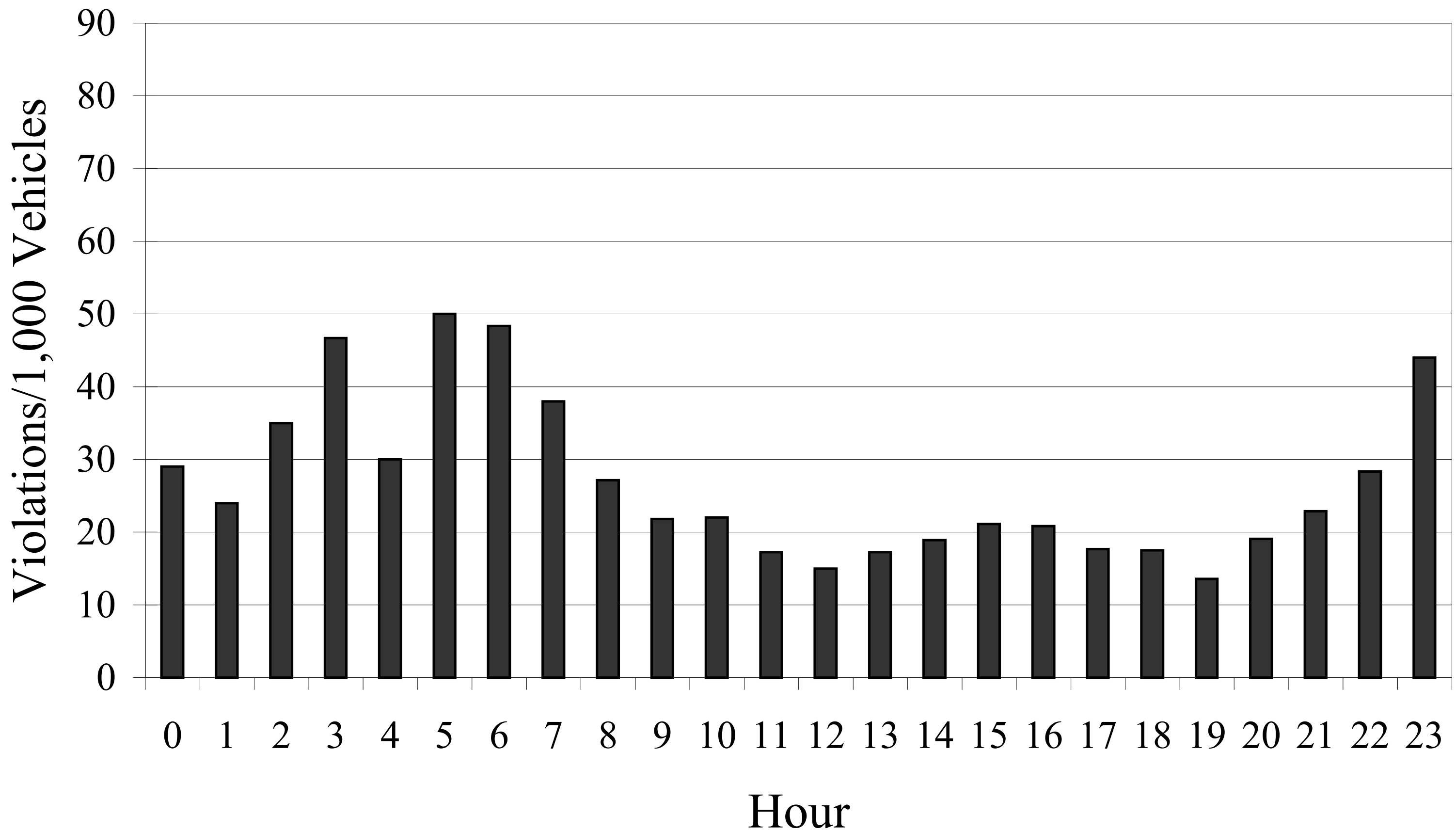


Figure B14. Hourly Violation Rates-Weekends



APPENDIX C
SPEED ANALYSIS

INTRODUCTION

The present Appendix contains information pertaining to the sign speed reduction effectiveness discussion in the body of the report. **Table C1** presents the days and the hours during which speed data was collected at the PC using a laser gun. **Table C2** presents the sign threshold criteria that were uploaded to the system on September 13, 2002. The numbers of violators during laser gun data collection hours before and after sign unveiling/operation are presented in **Table C3**.

Tables C4 and **C5** present speed findings for smaller vehicles (classes 2 and 3). **Table C4** provides **Figure 2** information in numerical form. **Table C5** provides statistical tests for all possible differences between the eight averages presented in **Figure 2**. The differences of critical importance to this evaluation, corresponding to the four stated hypotheses:

> $\mathbf{H_1}$: Speeds at the PC were lower for violators after sign installation;
> $\mathbf{H_2}$: Speeds at the PC remained unchanged for non-violators after sign installation;
> $\mathbf{H_3}$: Speeds at the detectors remained unchanged for violators after sign installation; and,
> $\mathbf{H_4}$: Speeds at the detectors remained unchanged for non-violators after sign installation,

are shown in **bold** type. Thus, for example, the line to the right of the symbol $\mathbf{H_1}$ provides statistics on whether violator speeds at the PC in the before period were statistically significantly different than violator speeds at the PC in the after period. Differences that are statistically significant at the 0.05 significance level are indicated by an asterisk next to the average difference of the two speeds being compared.

Similarly, **Tables C6** and **C7** address single-unit truck statistics, and **Tables C8** and **C9** semi-truck statistics.

It should be kept in mind that a **statistically** significant difference may not be of **practical** importance. For example, a speed difference of -0.633 mph was found among semi-truck non-violators between the before and the after period at the detector location (**Table C9**, $\mathbf{H_4}$). This difference is so small as to not have any practical importance.

Table C1. Laser Gun Speed Data Collection Dates and Hours; Number of Observations Collected During These Hours at the PC and the Detectors.

Before sign unveiling	***Time***	***Number of Observations***	
		At the PC	***At the Detectors***
Sunday, September 8, 2002	7:05 am -8:57 am	361	2390
Wednesday, September 11, 2002	9:40 am -10:25 am	195	2366
Thursday, September 12, 2002	10:55 am -12:00 pm	280	3767
Friday, September 13, 2002	10:20 am -11:22 am	198	3921
Sunday, September 15, 2002	9:30 am -10:25 am	300	2101
Subtotal		**1,334**	**14,545**
After sign unveiling			
Sunday, September 22, 2002	7:55 am -8:57 am	300	1531
Monday, September 23, 2002	10:29 am -11:28 am	299	3324
Wednesday, September 25, 2002	10:19 am -11:24 am	300	3630
Thursday, September 26, 2002	9:34 am -10:48 am	297	4268
Friday, September 27, 2002	11:10 am -12:07 pm	300	3853
Subtotal		**1,496**	**16,606**
Total		**2,830**	**31,151**

Table C2. Sign Threshold Values in Place Since September 13, 2002.

```
Class = 1 and      SPEED (MPH) ≥ 70  and   GVW (KIPS) ≥ 0.3
Class = 2 and      SPEED (MPH) ≥ 70  and   GVW (KIPS) ≥ 1.5
Class = 3 and      SPEED (MPH) ≥ 70  and   GVW (KIPS) ≥ 2.0
Class = 4 and      SPEED (MPH) ≥ 62  and   GVW (KIPS) ≥ 7.0
Class = 5 and      SPEED (MPH) ≥ 62  and   GVW (KIPS) ≥ 7.0
Class = 6 and      SPEED (MPH) ≥ 60  and   GVW (KIPS) ≥ 12.0
Class = 7 and      SPEED (MPH) ≥ 60  and   GVW (KIPS) ≥ 12.0
Class = 8 and      SPEED (MPH) ≥ 58  and   GVW (KIPS) ≥ 18.0
Class = 9 and      SPEED (MPH) ≥ 57  and   GVW (KIPS) ≥ 20.0
Class = 10 and     SPEED (MPH) ≥ 57  and   GVW (KIPS) ≥ 25.0
Class = 11 and     SPEED (MPH) ≥ 55  and   GVW (KIPS) ≥ 25.0
Class = 12 and     SPEED (MPH) ≥ 55  and   GVW (KIPS) ≥ 25.0
Class = 13 and     SPEED (MPH) ≥ 55  and   GVW (KIPS) ≥ 25.0
```

Sign would be actuated if all three conditions on any line are met. Vehicle classes are listed in **Table B1.**

Table C3. Percent Violators. Laser Gun Study Hours Only.

Vehicle type	**Vehicle classes**	**Automatic Data Recorder**	
		Before	**After**
1 Small vehicles	1,2,3	0.7% (n = 97)	0.5% (n = 75)
2 Single-Unit trucks	4,5,6,7	6.6% (n = 33)	6.0% (n = 37)
3 Semi-trucks	8,9	29.2% (n = 173)	28.1%(n = 238)

Note: The term “Single-unit trucks” is used for brevity. This vehicle type includes all vehicles larger than a pick-up truck, and smaller than a combination vehicle; it includes buses.

Table C4. Smaller Vehicle Average Speeds (see Figure 2).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before @ Detector Viol	97	72.752	2.7363	.2778	72.200	73.303	70.4	82.6
Before @ Detector Non-Viol	13314	57.986	4.5134	.0391	57.909	58.062	4.9	83.3
Before @ PC Viol	7	69.429	1.6183	.6117	67.932	70.925	67.0	71.0
Before @ PC Non-Viol	846	57.850	4.1964	.1443	57.567	58.133	44.0	71.0
After @ Detector Viol	74	72.296	2.4253	.2819	71.734	72.858	70.1	80.2
After @ Detector Non-Viol	15027	58.029	4.3859	.0358	57.959	58.099	7.1	75.8
After @ PC Viol	36	63.028	5.2887	.8815	61.238	64.817	53.0	74.0
After @ PC Non-Viol	902	57.897	4.0761	.1357	57.631	58.163	43.0	71.0
Total	30303	58.091	4.5600	.0262	58.040	58.143	4.9	83.3

Table C5. Smaller Vehicle Mean Speed Differences.

(I) Period, Location, Violator	(J) Period, Location, Violator	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Before @ Detector Viol	Before @ Detector Non-Viol	14.766*	.4506	.000	13.883	15.649
	Before @ PC Viol	3.323	1.7304	.055	-.069	6.715
	Before @ PC Non-Viol	14.902*	.4740	.000	13.973	15.831
H_3 →	**After @ Detector Viol**	**.456**	**.6824**	**.504**	**-.882**	**1.793**
	After @ Detector Non-Viol	14.723*	.4504	.000	13.840	15.606
	After @ PC Viol	9.724*	.8629	.000	8.032	11.415
	After @ PC Non-Viol	14.855*	.4724	.000	13.929	15.781
Before @ Detector Non-Viol	Before @ PC Viol	-11.443*	1.6716	.000	-14.719	-8.167
	Before @ PC Non-Viol	.136	.1568	.386	-.171	.443
	After @ Detector Viol	-14.310*	.5154	.000	-15.320	-13.300
H_4 →	**After @ Detector Non-Viol**	**-.043**	**.0526**	**.413**	**-.146**	**.060**
	After @ PC Viol	-5.042*	.7379	.000	-6.488	-3.596
	After @ PC Non-Viol	.089	.1521	.560	-.209	.387
Before @ PC Viol	Before @ PC Non-Viol	11.579*	1.6780	.000	8.290	14.868
	After @ Detector Viol	-2.867	1.7484	.101	-6.294	.560
	After @ Detector Non-Viol	11.400*	1.6715	.000	8.124	14.676
H_1 →	**After @ PC Viol**	**6.401***	**1.8264**	**.000**	**2.821**	**9.981**
	After @ PC Non-Viol	11.532*	1.6776	.000	8.244	14.820
Before @ PC Non-Viol	After @ Detector Viol	-14.446*	.5360	.000	-15.497	-13.396
	After @ Detector Non-Viol	-.179	.1562	.252	-.485	.127
	After @ PC Viol	-5.178*	.7524	.000	-6.653	-3.703
H_2 →	**After @ PC Non-Viol**	**-.047**	**.2116**	**.824**	**-.462**	**.368**
After @ Detector Viol	After @ Detector Non-Viol	14.267*	.5152	.000	13.257	15.277
	After @ PC Viol	9.268*	.8984	.000	7.507	11.029
	After @ PC Non-Viol	14.399*	.5346	.000	13.351	15.447
After @ Detector Non-Viol	After @ PC Viol	-4.999*	.7378	.000	-6.445	-3.553
	After @ PC Non-Viol	.132	.1516	.384	-.165	.429
After @ PC Viol	After @ PC Non-Viol	5.131*	.7515	.000	3.658	6.604

Based on observed means.
* The mean difference is significant at the .05 level.

Table C6. Single-Unit Truck Average Speeds (see Figure 3).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before @ Detector Viol	33	62.579	1.4853	.2586	62.052	63.105	60.3	65.7
Before @ Detector Non-Viol	472	54.634	5.4417	.2505	54.142	55.126	4.9	69.5
Before @ PC Viol	5	60.800	1.7889	.8000	58.579	63.021	59.0	63.0
Before @ PC Non-Viol	150	53.367	3.8659	.3156	52.743	53.990	38.0	62.0
After @ Detector Viol	37	63.711	2.6135	.4297	62.839	64.582	60.0	71.8
After @ Detector Non-Viol	585	54.674	5.5411	.2291	54.224	55.124	4.9	63.4
After @ PC Viol	18	55.667	4.5114	1.0634	53.423	57.910	44.0	62.0
After @ PC Non-Viol	166	53.404	3.7691	.2925	52.826	53.981	40.0	63.0
Total	1466	54.823	5.4118	.1413	54.545	55.100	4.9	71.8

Table C7. Single-Unit Truck Mean Speed Differences.

(I) Period, Location, Violator	(J) Period, Location, Violator	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Before @ Detector Viol	Before @ Detector Non-Viol	7.945*	.9086	.000	6.162	9.727
	Before @ PC Viol	1.779	2.4216	.463	-2.971	6.529
	Before @ PC Non-Viol	9.212*	.9702	.000	7.309	11.115
H_3 →	**After @ Detector Viol**	**-1.132**	**1.2082**	**.349**	**-3.502**	**1.238**
	After @ Detector Non-Viol	7.905*	.9028	.000	6.134	9.676
	After @ PC Viol	6.912*	1.4786	.000	4.012	9.812
	After @ PC Non-Viol	9.175*	.9618	.000	7.289	11.062
Before @ Detector Non-Viol	Before @ PC Viol	-6.166*	2.2686	.007	-10.616	-1.716
	Before @ PC Non-Viol	1.267*	.4730	.007	.340	2.195
	After @ Detector Viol	-9.077*	.8615	.000	-10.767	-7.387
H_4 →	**After @ Detector Non-Viol**	**-.040**	**.3122**	**.899**	**-.652**	**.573**
	After @ PC Viol	-1.033	1.2118	.394	-3.410	1.345
	After @ PC Non-Viol	1.230*	.4553	.007	.337	2.124
Before @ PC Viol	Before @ PC Non-Viol	7.433*	2.2940	.001	2.934	11.933
	After @ Detector Viol	-2.911	2.4043	.226	-7.627	1.805
	After @ Detector Non-Viol	6.126*	2.2663	.007	1.681	10.572
H_1 →	**After @ PC Viol**	**5.133***	**2.5509**	**.044**	**.130**	**10.137**
	After @ PC Non-Viol	7.396*	2.2904	.001	2.904	11.889
Before @ PC Non-Viol	After @ Detector Viol	-10.344*	.9262	.000	-12.161	-8.527
	After @ Detector Non-Viol	-1.307*	.4618	.005	-2.213	-.401
	After @ PC Viol	-2.300	1.2587	.068	-4.769	.169
H_2 →	**After @ PC Non-Viol**	**-.037**	**.5685**	**.948**	**-1.152**	**1.078**
After @ Detector Viol	After @ Detector Non-Viol	9.037*	.8554	.000	7.359	10.715
	After @ PC Viol	8.044*	1.4501	.000	5.200	10.889
	After @ PC Non-Viol	10.307*	.9174	.000	8.508	12.107
After @ Detector Non-Viol	After @ PC Viol	-.993	1.2075	.411	-3.362	1.376
	After @ PC Non-Viol	1.270*	.4437	.004	.400	2.141
After @ PC Viol	After @ PC Non-Viol	2.263	1.2522	.071	-.193	4.719

Based on observed means.
* The mean difference is significant at the .05 level.

Table C8. Semi-truck Average Speeds (see Figure 4).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before @ Detector Viol	173	59.305	1.7188	.1307	59.047	59.563	57.1	64.6
Before @ Detector Non-Viol	418	54.564	2.8869	.1412	54.287	54.842	43.8	64.6
Before @ PC Viol	99	56.788	2.6622	.2676	56.257	57.319	46.0	63.0
Before @ PC Non-Viol	154	52.942	2.8771	.2318	52.484	53.400	46.0	60.0
After @ Detector Viol	238	59.577	1.7162	.1112	59.358	59.796	57.1	66.9
After @ Detector Non-Viol	606	55.198	2.7626	.1122	54.977	55.418	44.7	68.6
After @ PC Viol	149	53.597	3.8833	.3181	52.969	54.226	42.0	63.0
After @ PC Non-Viol	219	53.288	3.2275	.2181	52.858	53.718	44.0	61.0
Total	2056	55.510	3.5176	.0776	55.357	55.662	42.0	68.6

Table C9. Semi-truck Mean Speed Differences.

(I) Period, Location, Violator	(J) Period, Location, Violator	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Before @ Detector Viol	Before @ Detector Non-Viol	4.740*	.2508	.000	4.248	5.232
	Before @ PC Viol	2.517*	.3496	.000	1.831	3.202
	Before @ PC Non-Viol	6.363*	.3074	.000	5.760	6.966
H_3 →	**After @ Detector Viol**	**-.273**	**.2772**	**.325**	**-.816**	**.271**
	After @ Detector Non-Viol	4.107*	.2391	.000	3.638	4.576
	After @ PC Viol	5.707*	.3101	.000	5.099	6.315
	After @ PC Non-Viol	6.017*	.2822	.000	5.464	6.570
Before @ Detector Non-Viol	Before @ PC Viol	-2.224*	.3101	.000	-2.832	-1.615
	Before @ PC Non-Viol	1.623*	.2615	.000	1.110	2.136
	After @ Detector Viol	-5.013*	.2253	.000	-5.455	-4.571
H_4 →	**After @ Detector Non-Viol**	**-.633***	**.1764**	**.000**	**-.979**	**-.287**
	After @ PC Viol	.967*	.2647	.000	.448	1.486
	After @ PC Non-Viol	1.277*	.2314	.000	.823	1.731
Before @ PC Viol	Before @ PC Non-Viol	3.846*	.3574	.000	3.145	4.547
	After @ Detector Viol	-2.789*	.3318	.000	-3.440	-2.139
	After @ Detector Non-Viol	1.590*	.3007	.000	1.001	2.180
H_1 →	**After @ PC Viol**	**3.191***	**.3597**	**.000**	**2.485**	**3.896**
	After @ PC Non-Viol	3.500*	.3360	.000	2.841	4.159
Before @ PC Non-Viol	After @ Detector Viol	-6.636*	.2869	.000	-7.198	-6.073
	After @ Detector Non-Viol	-2.256*	.2504	.000	-2.747	-1.765
	After @ PC Viol	-.656*	.3188	.040	-1.281	-.031
H_2 →	**After @ PC Non-Viol**	**-.346**	**.2918**	**.236**	**-.918**	**.226**
After @ Detector Viol	After @ Detector Non-Viol	4.380*	.2122	.000	3.964	4.796
	After @ PC Viol	5.980*	.2898	.000	5.412	6.548
	After @ PC Non-Viol	6.290*	.2598	.000	5.780	6.799
After @ Detector Non-Viol	After @ PC Viol	1.600*	.2537	.000	1.103	2.098
	After @ PC Non-Viol	1.910*	.2187	.000	1.481	2.339
After @ PC Viol	After @ PC Non-Viol	.310	.2946	.293	-.268	.887

Based on observed means.
* The mean difference is significant at the .05 level.

APPENDIX D
CRASH ANALYSIS

INTRODUCTION

The analysis presented herein was performed in order to identify crash characteristics at the study site, with a focus on speed-related crashes, taking into account vehicle size. Appendix figures and tables present involved vehicle size, time of day, pavement and light condition, crash severity (presence of personal injury), crash type and manner of collision characteristics.

Identified crash characteristics may be used as inputs in the decision-making process to set sign threshold criteria for large and small vehicles. For example, sign settings could be such, that targeted violator percentages for a given vehicle size reflect the proportion of speed-related crashes among vehicles of the same size. Such an objective could be fine-tuned by selecting appropriate speed thresholds, using speed analysis data.

Because it was desired to address impacts of the evaluated device separately for trucks, crashes were classified into those involving "small" vehicles only, and those involving at least one "large" vehicle.[1]

CRASH RATES

Crash records were reviewed in order to identify crashes that occurred between the sign bridge location and Brown Avenue (segment length 0.45 mile). A total of 277 crashes occurred within this segment between January 1, 1996 and December 31, 2001.

The average (bi-directional) daily traffic at the study location was 126,600 vpd [2] during the analyzed period. Given that the southbound direction carried 50% of the daily traffic, crash rate at the study site was:

$$\frac{277 \times 10^8}{(126{,}600 \times 0.50) \times 365 \times 6 \times 0.45} = 444.04 \text{ crashes per hundred million vehicle miles of travel}$$

In considering this crash rate, it should be kept in mind that, despite the relatively long analysis period of six years, which has a crash rate smoothing effect, the short study segment length induces very substantial year-to-year crash rate variation.

Table D1 provides crash rates for small and large vehicles. Crash rates for speed-related crashes are approximately three times higher for large vehicles compared to small vehicles.

[1] Large vehicle: bus (including school bus), utility truck, straight (insert) truck, truck tractor (not attached, semi attached, double bottom). These vehicles correspond to vehicle classes >3 —see **Table B1**.
Small vehicle: passenger car or light truck. These vehicles correspond to vehicle classes 2 and 3.

[2] Based on the Vine Street permanent recorder, located approximately 0.25 miles south of the study location. The recorder indicated 136,100 vpd; North Avenue ramp traffic was 9,500 vpd.

Table D1. Crash Rates for Small and Large Vehicles.

Vehicle type	Crash Rate (crashes/100 million-vehicle miles)	
	Overall	Speed-Related
Small	359	260
Large	1732	776

Crash rates were calculated for each hour of the day, separately for weekdays and weekends (**Figures D3 and D4**, respectively). Both figures indicate that the highest crash rates were experienced during the early morning hours, when traffic volumes were lower (until 4 am on weekdays and until 8 am on weekends).[3] These hours correlate well with the hours when the highest violation rates were recorded (see **Figures B13 and B14**).

SPEED-RELATED CRASHES

Speed-related crashes were defined as those that involved a single vehicle, or any crash where a driver was cited for failure to keep the vehicle under control, speeding, or driving too fast for conditions.

WEEKDAY/WEEKEND CRASH HOUR RELATIONS WITH VOLUME AND SPEED

The speed analysis section of the report indicates that weekday and weekend average speed patterns were distinct, and corresponded to traffic volume patterns, with higher speeds during lower volume hours and vice-versa. Weekdays exhibited two distinct peak volume periods. The morning peak occurred between 6 and 9 am. Volumes peaked at 5,600 vph between 7 and 8 am when speeds dropped by 9 – 10 mph. During this hour speed differences between small and larger vehicles were less than 2 mph. Although the afternoon peak volume (4,250 vph) occurred between 5 and 6 pm, lower than mid-day speeds were present between 2 and 6 pm, and the lowest speeds were recorded between 3 and 4 pm; these speeds were due to downstream congestion.

During weekends, volumes remained at their highest levels (approximately 3,600 vph) between 10 am and 8 pm.

Figures D1 and **D2** present a summary of weekday and weekend crashes, respectively. Weekday speed-related crashes were fewer during the am and the pm high-volume hours—non-speed-related crashes were at their highest levels during these hours. During the mid-day period there was a mix of both types of crashes. The presence of speed-related crashes during these hours was expected, given that traffic volumes were relatively low, and free-flow speeds were experienced quite often between peaks at the study location. Speed-related crashes were prevalent in late evening and early morning hours.

[3] Weekday crash rates are based on more crashes than weekend crash rates, and are thus more reliable.

The weekend was dominated by speed-related crashes, as expected, due to lower traffic volumes and a prevalence of free-flow speeds.

Figures D3 and D4 present weekday and weekend hourly crash rates (crashes per million vehicle-miles of travel) for speed-related crashes. Crash rates are much higher during low-volume hours, although average speeds during these hours are not different than midday speeds.

VEHICLE SIZE

Tables D1 through D5 present crash statistics for small and large vehicles, in relation to road and light conditions, crash severity, crash type and manner of collision. Small differences in table grand totals are due to missing information for analyzed variables.

The majority of crashes at the study location (66%) were speed-related. Speed-related crashes that involved only small vehicles constituted 84% of these crashes (small vehicle presence in the traffic stream was 93% on weekdays and 97% on weekends); the remainder involved at least one large vehicle. It is interesting to note that 73% of small vehicle crashes were speed related; 45% of crashes involving at least one large vehicle were speed-related.

Approximately 46% of all crashes occurred on wet pavement; 84% of those crashes were speed-related (**Table D1**). Crashes under dark-lighted conditions represented 36% of the total; 85% of small vehicle and 56% of large vehicle crashes under these conditions were speed-related (**Table D2**).

Injury crashes constituted 36% of all crashes (average for the Milwaukee County freeway system was 32% during the analysis period[4]). Among injury crashes, 70% were speed-related (**Table D3**). The one listed fatal crash occurred at 5 pm (dusk), on Tuesday, December 21, 1999. It involved a single passenger car traveling on dry pavement and hitting a bridge pier.

The majority of non-speed-related crashes involved collisions with other motor vehicles (93%--**Table D4**). Most speed-related crashes (63%) did not involve collisions with motor vehicles; among them, 45% involved collisions with the median barrier. Among collisions with another motor vehicle, 44% were speed-related.

Rear-end crashes and crashes not involving another motor vehicle were prevalent, at approximately 40% each. Speed-related crashes were 34% of rear-end collisions. Among these collisions, distinct patterns were evident for large and small vehicles, with 16% among large vehicle crashes, and 41% among small vehicle crashes being speed-related (**Table D5**).

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[4] Wisconsin Traffic Crash Facts 1996 – 2001, prepared by the Bureau of Transportation Safety, Division of Transportation Investment Management.

SUMMARY

Among speed-related crashes, 84% involved small vehicles only (93-97% of the traffic was small vehicles).

Crash rates for speed-related crashes were three times higher for large vehicles than small vehicles.

Speed-related crashes were:

- 66% of all crashes.
- 73% of small vehicle crashes.
- 45% of heavy vehicle crashes.
- 84% of all crashes on wet pavement.
- 80% of crashes under dark-lighted conditions.
- 70% of injury crashes.
- 44% of crashes with another motor vehicle.
- 34% of rear-end crashes.

Speed-related crashes during weekdays:

- Peaked between the morning and the afternoon peak volume hours.
- Dominated the period between the pm peak and the am peak.
- Were few during the highest peak of the day (am peak).

Non-speed-related crashes during weekdays:

- Peaked during peak traffic volume hours.
- Were present during mid-day hours
- Were uncommon during nighttime.

Most weekend crashes were speed-related.

Figure D1. Weekday Crashes.

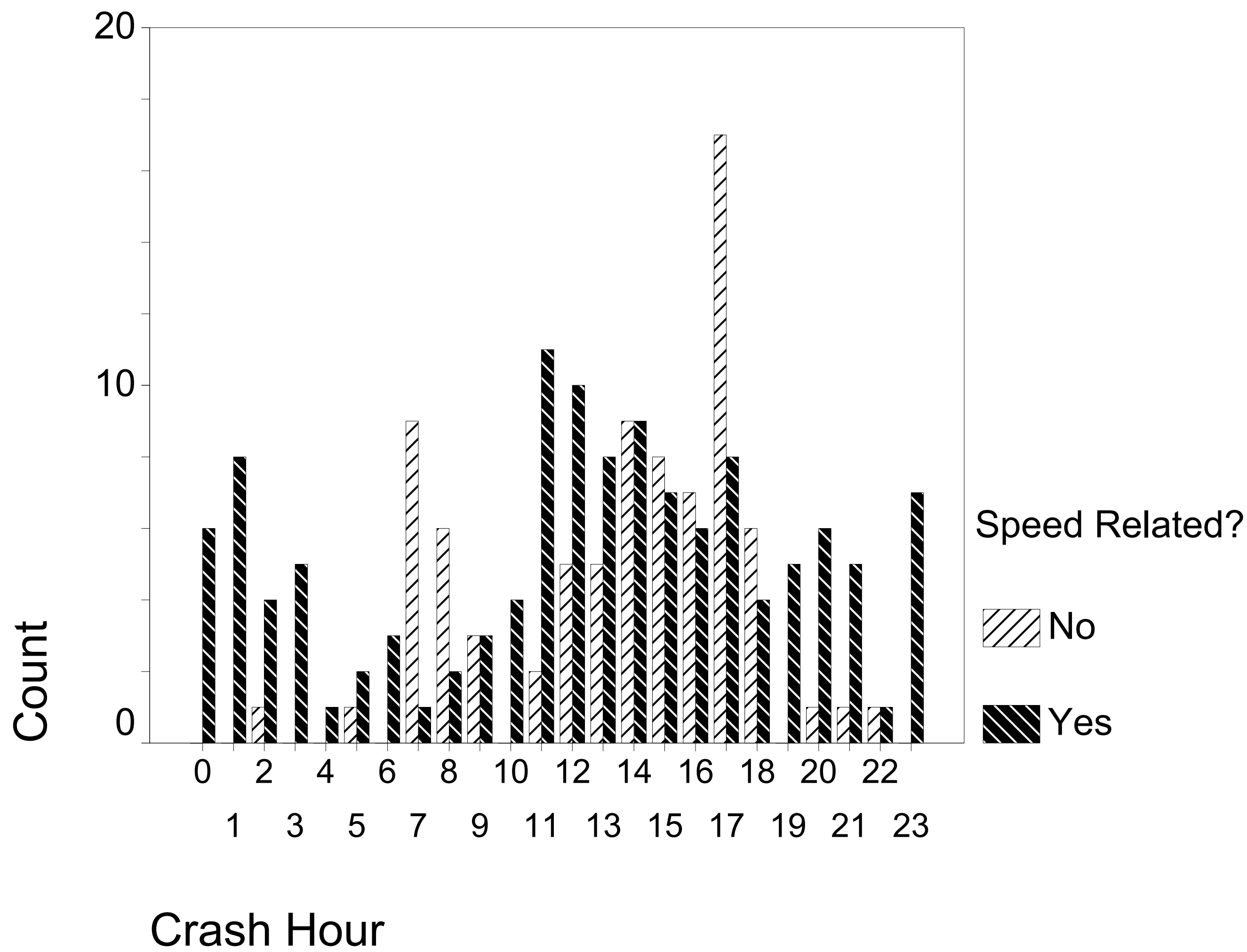

Figure D2. Weekend Crashes.

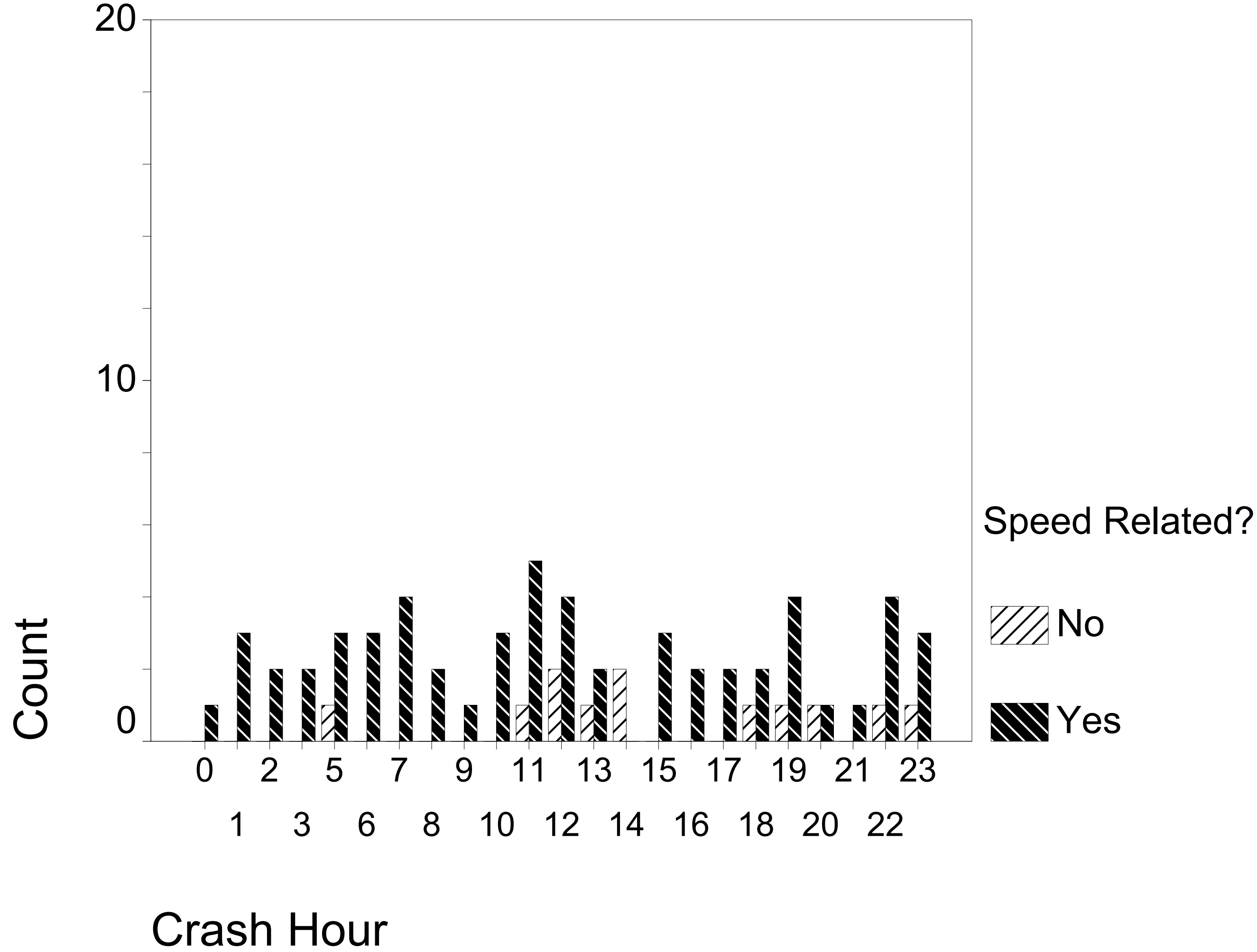

Figure D3. Speed-Related Crashes-Weekdays

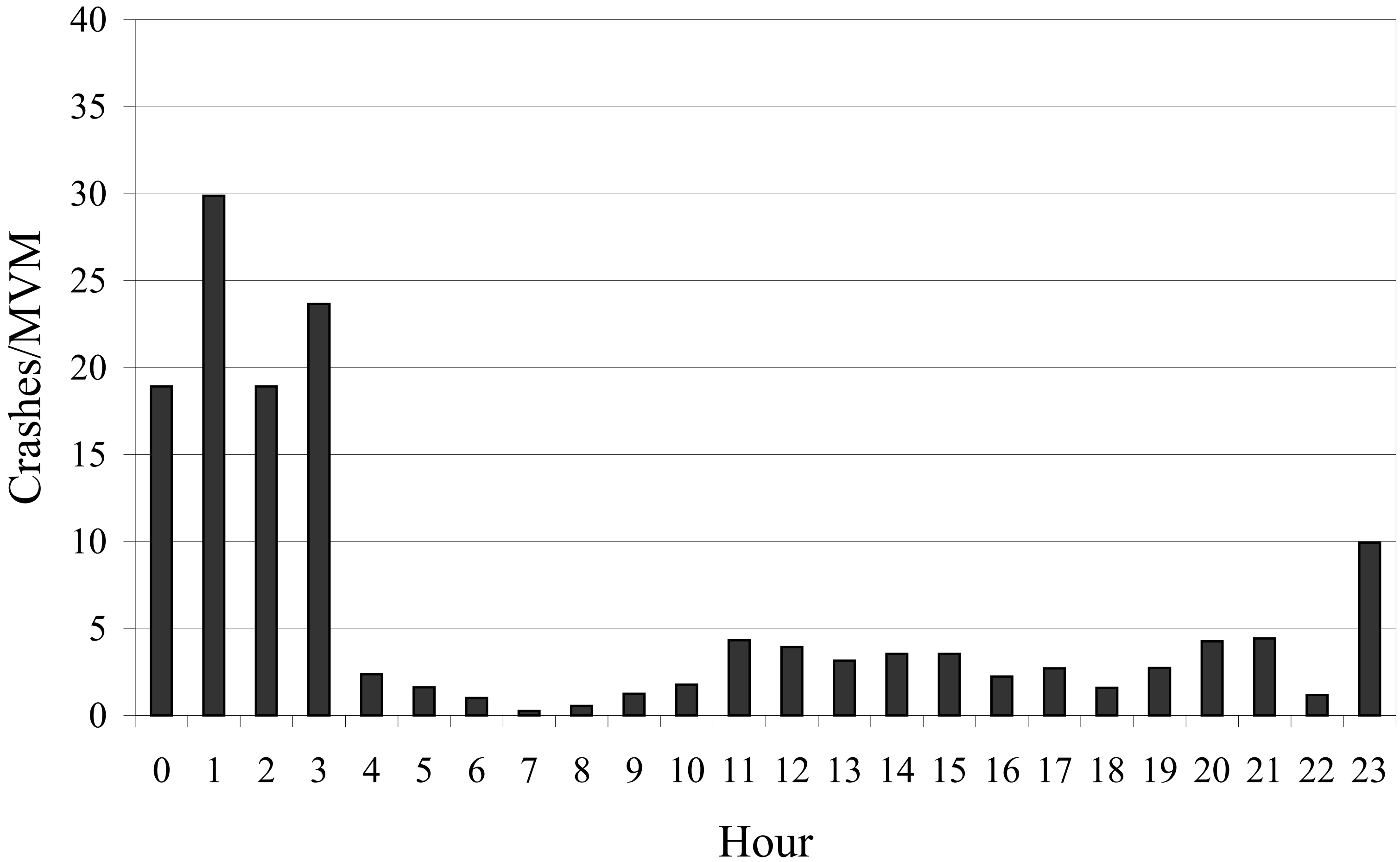

Figure D4. Speed-Related Crashes-Weekends

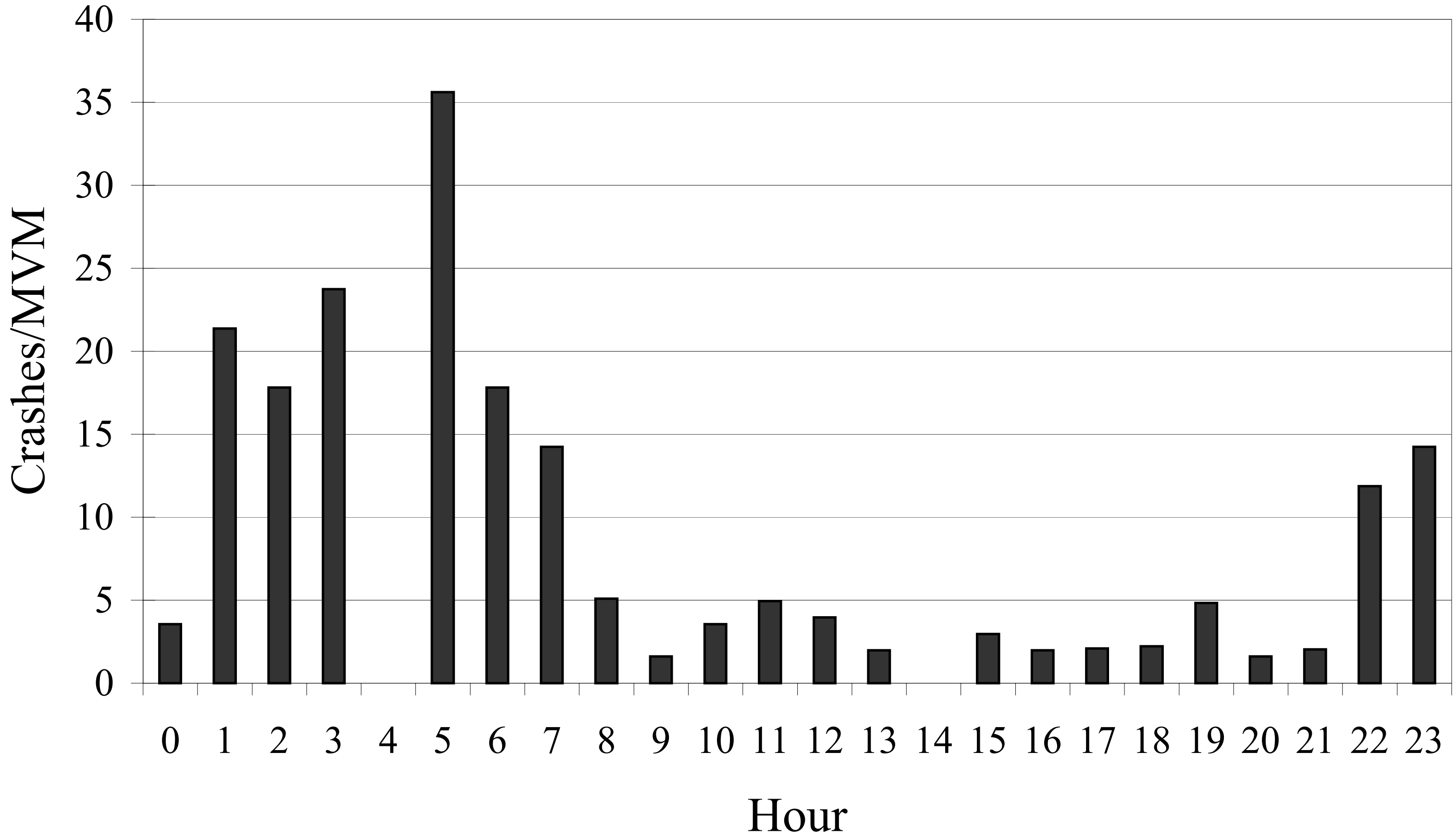

Figure D5. Wet Pavement Speed-Related Crashes-Weekdays

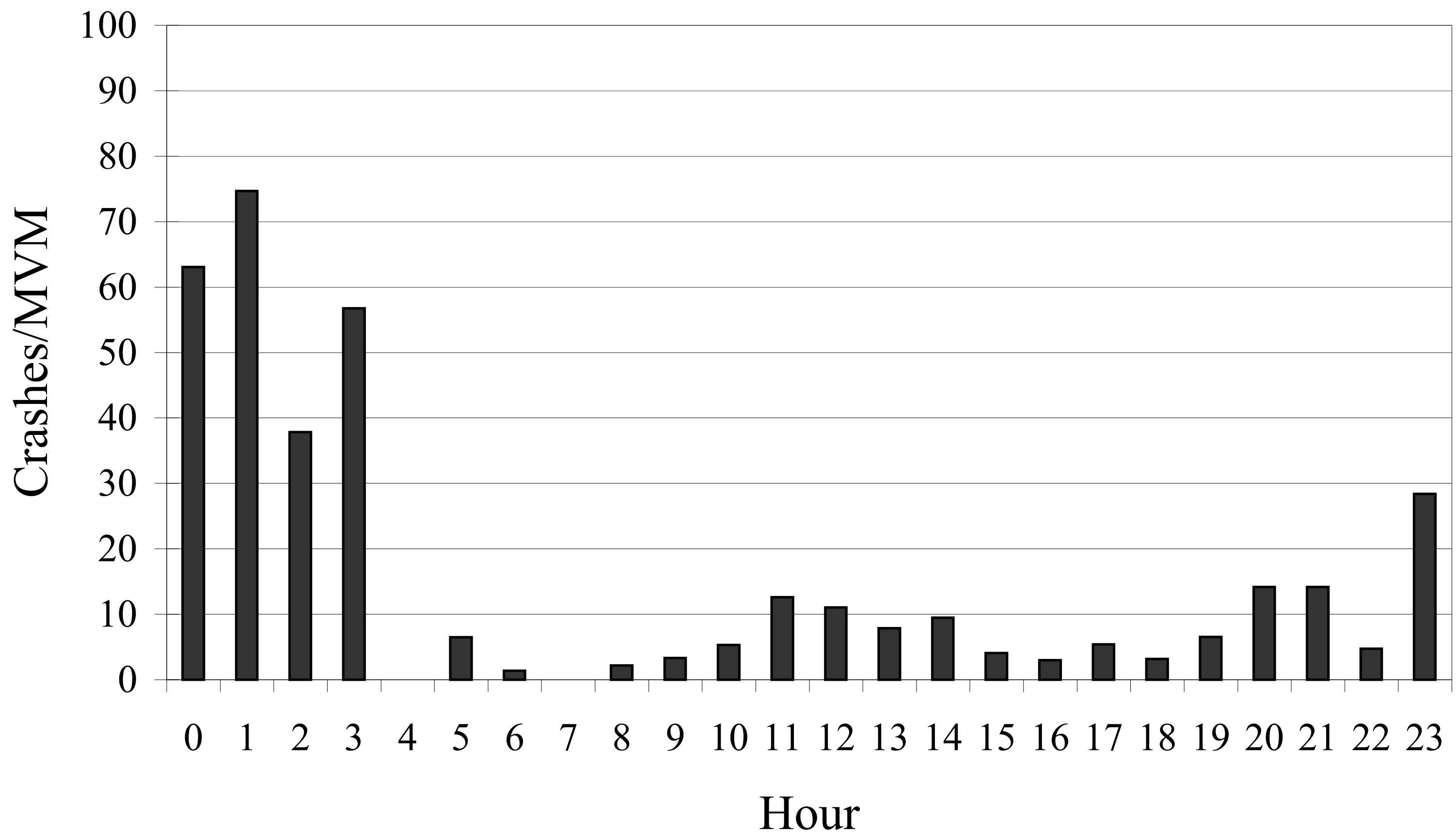

Figure D6. Wet Pavement Speed-Related Crashes-Weekends

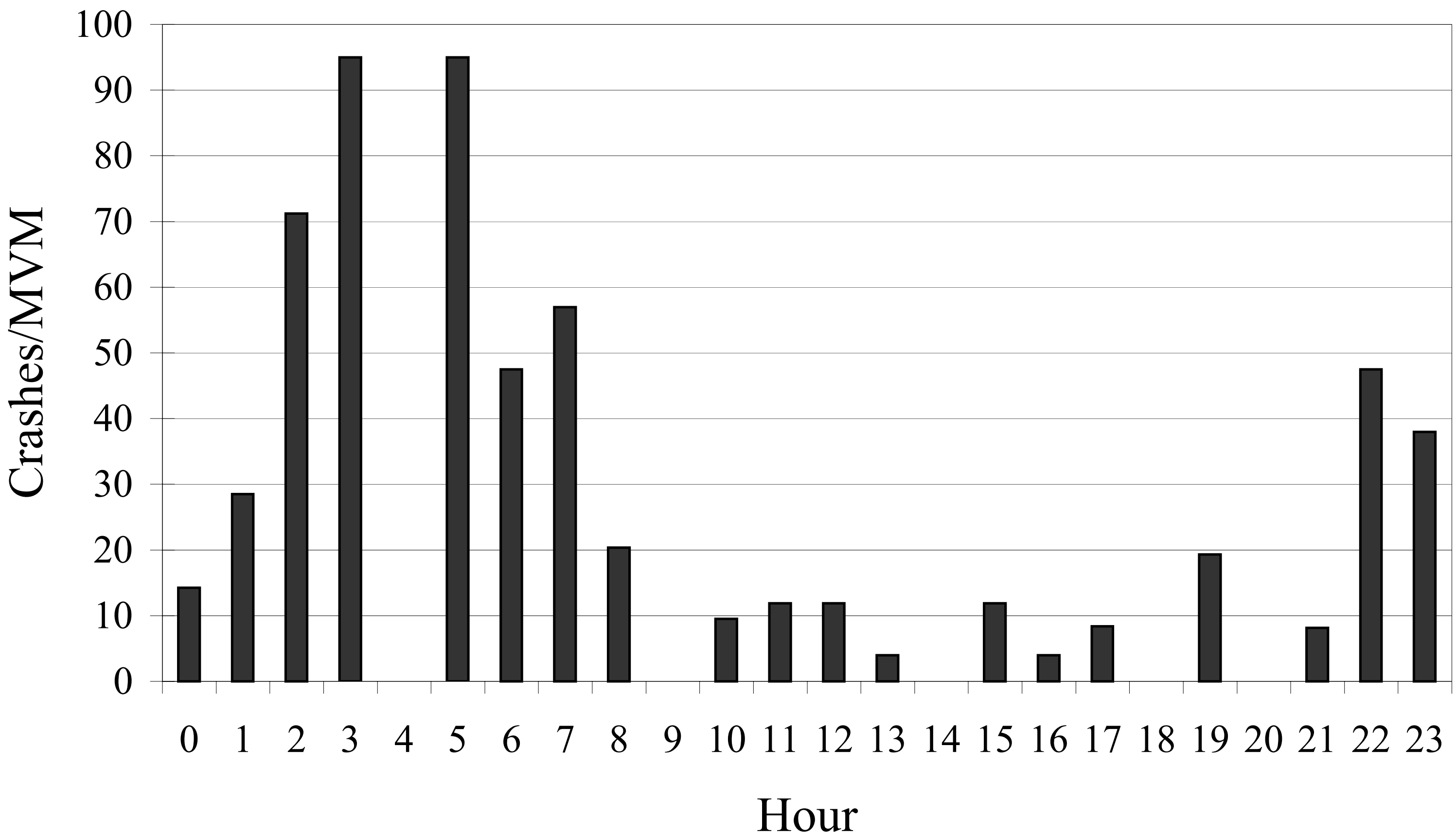

Table D2. Speed-Related Crashes by Road Condition.

		Involved Vehicles				
		Large		Small		
		Speed Related?		Speed Related?		
		No	Yes	No	Yes	Table Total
Road Conditions	Dry	27	8	44	53	132
	Mud	1				1
	Snow	1	4		11	16
	Wet	7	18	13	88	126
Table Total		36	30	57	152	275

Table D3. Speed-Related Crashes by Light Condition.

		Involved Vehicles				
		Large		Small		
		Speed Related?		Speed Related?		
		No	Yes	No	Yes	Table Total
Light Condition	Daylight	29	20	43	79	171
	Dusk			2	4	6
	Dark-Lighted	8	10	12	70	100
Table Total		37	30	57	153	277

Table D4. Speed-Related Crashes by Crash Severity.

		Involved Vehicles				
		Large		Small		
		Speed Related?		Speed Related?		
		No	Yes	No	Yes	Table Total
Crash Severity	Fatal				1	1
	Injury	9	12	21	57	99
	Property	28	18	36	95	177
Table Total		37	30	57	153	277

Table D5. Speed-Related Crashes by Crash Type.

		Involved Vehicles				
		Large		Small		
		Speed Related?		Speed Related?		
		No	Yes	No	Yes	Table Total
Crash Type	Collision w/MV	33	12	54	56	155
	Bridge Pier		3		5	8
	Curb				1	1
	Fire				2	2
	Jacknife		4			4
	Light Pole				1	1
	Median Barrier	2	10	2	72	86
	Non-Fixed Object	1			5	6
	Non-Collision				3	3
	Other Fixed Object				2	2
	Overturn		1		1	2
	Parked Vehicle	1		1	2	4
	Traffic Sign				1	1
	Tree				1	1
Table Total		37	30	57	152	276

Table D6. Speed-Related Crashes by Manner of Collision.

		Involved Vehicles				Table Total
		Large		Small		
		Speed Related?		Speed Related?		
		No	Yes	No	Yes	
Manner of Collision	Angle	1	2	1	13	17
	Head-On		1			1
	No Coll w/MV[a]	2	17	3	91	113
	Rear-End	26	5	47	33	111
	Side-Swipe Same[b]	8	5	6	15	34
Table Total		37	30	57	152	276

a. No Collision with Motor Vehicle

b. Side-Swipe Same Direction