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EFFECTIVENESS OF SPEED MINDERS IN REDUCING DRIVING SPEEDS ON RURAL HIGHWAYS IN PENNSYLVANIA

PennDOT/MAUTC Partnership
Research Agreement No. 510401

FINAL REPORT

June 2008

By E. T. Donnell and I. Cruzado

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16. Abstract

The objective of this project was to determine the effectiveness of dynamic speed display signs (also known as "speed minders") in reducing vehicle operating speeds. The Pennsylvania Department of Transportation (PennDOT) has invested in several speed minders. Each engineering district uses the speed minders in an effort to assist in managing vehicle speeds, particularly in locations where the roadway transitions from a high-speed (45 to 55 mph) to low-speed (25 to 35 mph) operating environment. It is common for these regulatory speed limit changes to occur along roadways that pass through rural communities. PennDOT selected several locations in central Pennsylvania to position the speed minder signs to evaluate their effectiveness. These locations were primarily along roadways that transition from high-speed to low-speed operations on rural highways; however, several locations were on roadways without regulatory speed changes. Because each engineering district has only a few speed minder devices, it is common that they are placed and activated at a site for a period of 1 week and then rotated to other roadways within the district to provide greater geographic coverage. The objective of this project was to determine the effectiveness of speed minders in reducing vehicle operating speeds. At all evaluation locations, an observational before-during-after study approach was used. The study findings suggest that while deploying speed minders for a period of 1 week has the desired effect of reducing mean speeds while in place, after their removal speeds return to approximately the same level as prior to deployment. There may be a benefit associated with deploying speed minders for a long duration at sites in Pennsylvania, rather than deploying them for a single week.

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EFFECTIVENESS OF SPEED MINDERS IN REDUCING DRIVING SPEEDS ON RURAL HIGHWAYS IN PENNSYLVANIA

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1.0 INTRODUCTION

Approximately 30 percent of all fatal motor vehicle crashes are related to speeding (NHTSA, 2006). Driver compliance with posted speed limits requires that speed regulations be reasonable. Additionally, driver compliance is a function of the public's willingness to obey, and the consistent enforcement of, the speed limit regulation. Although speed enforcement is an effective method to manage speeds, it requires significant resources to ensure adequate spatial and temporal compliance. In some cases, other enforcement methods may be necessary to deter drivers that travel in excess of the posted speed limit. One such method is via the use of dynamic speed display signs that serve to help motorists "self-enforce" their speed.

Dynamic speed display signs (also known as "speed minders") measure the speed of approaching vehicles and communicate the speed to drivers on a digital display. An example of a dynamic speed display sign is shown in Figure 1. When coupled with a posted speed limit sign, the real-time display permits drivers to compare their operating speed to the regulatory speed.

Figure 1. Dynamic Speed Display Sign.

The Pennsylvania Department of Transportation (PennDOT) has invested in several speed minders. Each engineering district uses the speed minders in an effort to assist in managing vehicle speeds, particularly in locations where the roadway transitions from a high-speed (45 to 55 mph) to low-speed (25 to 35 mph) operating environment. It is common for these regulatory speed limit changes to occur along roadways that pass through rural communities. PennDOT selected several locations in central Pennsylvania to position the speed minder signs to evaluate their effectiveness. These locations were primarily along roadways that transition from high-speed to low-speed operations on rural highways; however, several locations are on roadways without regulatory speed changes. Because each engineering district has only a few speed minder devices, it is common that they are placed and activated at a site for a period of 1 week and then rotated to other roadways within the district to provide greater geographic coverage.

The objective of this project was to determine the effectiveness of speed minders in reducing vehicle operating speeds. At all evaluation locations, an observational before-during-after study approach was used. No police enforcement was present during the evaluation period. To accomplish the project objectives, the following tasks were performed:

- Review existing literature related to dynamic speed display sign evaluations. Efforts to use these signs to manage speeds in construction work zones, school zones, and other locations were all included in the literature review.

- Develop a data collection and analysis plan. The plan described site selection criteria, data collection methods, and analysis methods.

- Perform statistical tests of speed minder effectiveness based on before, during, and after period data. The before period consisted of the time prior to speed minder presence and serves as a baseline to compare vehicle operating speeds during and after speed minder presence. The "during" period consisted of the time period when the speed minder was present at the evaluation site. It was common for the "during" period to be limited to 1 week in order for PennDOT to implement the speed minders on a widespread geographic basis. The "after" period consisted of a 1-week time period after the speed minder was removed from the site. This time period served as an indication of how effective the speed minders were at reducing speeds after being removed from the site. At four locations, the speed minder device was implemented and activated for a period of 2 weeks. "During" data were collected once during each of these weeks to determine if the speed minder device was effective in reducing vehicle operating speeds for a longer time period than the usual 1-week period. At each of these sites, speed data were collected for 2 consecutive weeks after the speed minder was deactivated and removed from the study segment.

This report is organized into several sections. The next section (section 2) is a summary of the existing literature. Section 3 describes the site selection and data collection process. Section 4 describes the analysis methodology. Section 5 contains the analysis results. The last section (section 6) is a summary of the findings and contains preliminary recommendations for future speed minder applications in the Commonwealth of Pennsylvania.

2.0 LITERATURE REVIEW

Several studies have evaluated the effectiveness of dynamic speed display signs. Implementation of these signs has commonly occurred in construction work zones, near school zones, or in advance of horizontal curves. One previous research effort evaluated the use of dynamic speed display signs at locations that transition from high- to low-speed operations. This indicates that the present experiment is the first to evaluate dynamic speed display signs on a larger scale. In all past research studies, implementation of the dynamic speed display signs was either permanent or temporary. This section of the report synthesizes the existing research on dynamic speed display signs.

2.1 Use of Changeable Message Signs in Work Zones

Richards and Dudek (1986) evaluated four methods to obtain speed reductions in arterial and freeway work zones: flagging, law enforcement, changeable message signs (CMS), and lane width reductions. Among the advantages of CMS noted were that they are easy to implement and cause little or no disruption to traffic. The disadvantages of the CMS were that speed reductions were considered "modest" (less than 10 mph) and that their effectiveness decreased over time. Additionally, the implementation costs of the CMS were considered high, since these devices require routine repair and maintenance.

A study along Interstate 90 in South Dakota evaluated several traffic control devices designed to reduce speeds within work zones (McCoy et al., 1995). A speed monitoring display (SMD) sign was used in the study along with a traditional WORK ZONE sign and an advisory speed sign (45 mph). The work zone contained a right-lane closure. Two speed-monitoring display devices were placed within the work zone, one on the left shoulder at the beginning of the work zone and another on the right shoulder immediately before the right-lane closure. Speed data, before and after installation of the SMD devices, were collected at three locations along the study site: (1) at the beginning of the work zone, (2) next to the SMD sign, and (3) after closure of the right lane. After-data were collected 7 days after installation of the speed displays in order to eliminate the "novelty effect." Only speed data from free-flow vehicles, identified as those with headways greater than 4 seconds, were collected during favorable conditions (daylight hours and dry pavement). The results of the data analyses showed that mean speeds decreased by 4 to 5 mph (6 to 8 km/hr) approaching the work zone after the SMDs were implemented. Additionally, the results indicated that the number of two-axle vehicles exceeding the advisory speed limit (45 mph [72 km/hr]) by more than 10 mph (16 km/hr) decreased by 20 to 25 percent. The number of vehicles with more than two axles traveling at excessive speeds was reduced by 40 percent after SMD implementation.

Four different messages displayed on changeable message signs were evaluated by Garber and Patel (1995) along work zones with a reduction in the posted speed limit. The messages – EXCESSIVE SPEED SLOW DOWN, HIGH SPEED SLOW DOWN, REDUCE SPEED IN WORK ZONE, and YOU ARE SPEEDING SLOW DOWN – were tested at seven sites on Interstates in Virginia; six sites had speed limits of 55 mph within the work zone area, while the seventh site had a posted speed limit of 45 mph. All work zones were at least 1,500 ft long. Speed data were recorded at three locations along the work zone at all sites: (1) at the beginning of the transition area (Station 1), (2) at the midpoint of the work zone area (Station 2), and (3) just before the end of the work zone (Station 3). The CMS device was located between Stations 1 and 2. The speed data were categorized into two different speed groups: those traveling between 59 and 64 mph and those traveling at speeds of 65 mph and greater. The latter group was referred to as "high-speeding" vehicles. When considering all high-speeding vehicles, the mean speed reduction was 15.25 mph. The message that was associated with the highest reduction in operating speeds within the work zone was YOU ARE SPEEDING SLOW DOWN. The HIGH SPEED SLOW DOWN message was also associated with high speed reductions; statistical tests revealed that these two messages resulted in significant reductions in operating speeds, at both Stations 2 and 3, at the 95 percent confidence level. The message EXCESSIVE SPEED SLOW DOWN only experienced significant speed reductions at Station 3, while REDUCE SPEED IN WORK ZONE was associated with significant speed reductions at Station 2 only. Statistical tests revealed that all messages were effective in obtaining significant reductions in the 85th percentile operating speeds in work zones. Reductions in operating speeds at all sites were compared to a control site (without CMS) and tests showed that these differences were significant at the 95 percent confidence level. Speed variances at the study sites were also analyzed; the only message that was not associated with a significant difference in speed variance was EXCESSIVE SPEED SLOW DOWN. The authors concluded that CMS are more effective than standard MUTCD signs in reducing operating speeds and speed variance within work zones.

A subsequent study by Garber and Srinivasan (1998) evaluated CMS exposure in work zones along primary highways and Interstates in Virginia. All sites required speed reductions due to the presence of the work zone. Effectiveness tests of speed control techniques included CMS, MUTCD signs, and their combination. The authors targeted work zones that were at least 1,500 ft long in order to ensure that there was enough distance for drivers to vary their speeds. Speed data were collected after the first, third, fifth, and seventh week of installation of the devices. No before-data were collected, as the purpose of the evaluation was to assess the long-term effectiveness of the CMS devices. Data were recorded at the beginning, within, and at the end of the work zone (stations 1, 2, and 3 in Table 1 below). The CMS was located immediately following the first set of tubes and it displayed the message YOU ARE SPEEDING SLOW DOWN; this message was selected since previous studies found it to be the most effective in obtaining speed reductions. Mean and 85th percentile speeds were analyzed and statistical tests (t-tests) indicated that the there were significant reductions in speeds at all sites and at all post-implementation time periods. The mean speeds recorded at each observation location (station) are shown in Table 1 along with the average reduction in speeds between stations 1 and 2 and stations 1 and 3. The results shown in Table 1 indicate that the speed reductions were greater 3 or more weeks after CMS implementation when compared to the speed reductions obtained in the first week after implementation. These results were consistently observed for all vehicle classifications. In addition to the speed reduction evaluation, Garber and Srinivasan (1998) also evaluated the percentage of vehicles exceeding the speed limit. The results showed a significant reduction in the proportion of vehicles exceeding the posted speed limit at all sites.

Table 1. Average Speeds and Speed Reductions along Interstate 81 in Virginia (Garber and Srinivasan, 1998).

Period	Average Speeds (mph)			Speed Reduction (mph)	
	Station 1	Station 2	Station 3	Station 1→2	Station 1→3
Week 1	61.23	55.51	55.94	5.72	5.29
Week 3	61.68	54.86	55.06	6.82	6.62
Week 5	61.91	54.80	55.03	7.11	6.88
Week 7	61.83	54.74	55.80	7.09	6.03

Dixon and Wang (2002) also evaluated the effectiveness of various devices aimed at reducing operating speeds within median crossover work zones in Georgia. Changeable message signs with radar and different static signs were evaluated. The static signs, placed both to the left and right of the travel lanes, consisted of either standard high-intensity sheeting or fluorescent orange sheeting. The signs displayed a MY DAD (OR MOM) WORKS HERE DRIVE SLOWLY message. The CMS displayed a specific message depending on the speed magnitude in the work zone. YOU ARE SPEEDING, SLOW DOWN NOW was displayed for vehicles traveling 5 mph or more above the work zone speed limit (45 mph at the study site), and ACTIVE WORK ZONE, REDUCE SPEED for vehicles traveling less than 50 mph. Speed and volume data were collected using on-road sensors during three different periods: before implementation, immediately after implementation, and several weeks after implementation. Analyses of free-flow vehicles, identified as those with a minimum headway of no less than 5 seconds, revealed that speed reductions between 6 and 8 mph were obtained immediately after implementation of the CMS. Since the adjacent lane (opposite direction) experienced speed reductions up to 2 mph, the authors concluded that "a possible reduction of speed due to the CMS of 5 to 7 mph" was found. After 3 weeks, speed reductions did occur at the CMS test location while speeds in the opposing lane (i.e., comparison site) did not change. This suggests that the CMS was effective. After comparing these reductions with those obtained with the new static signs, the authors concluded that CMS has the greatest influence on speed reduction.

Chitturi and Benekohal (2006) evaluated the effectiveness of radar-based speed devices (feedback speed devices) in a work zone along a four-lane divided section of Interstate 70 in Illinois. A lane closure was present in the work zone along with a posted speed limit of 55 mph. Speed data were collected in three phases: before, immediately after installation, and 3 weeks after installation. The average vehicle operating speeds were 64.9 mph, 60.5 mph, and 58.2 mph, respectively. The results of the study showed that there was a consistent reduction in operating speeds due to the introduction of the speed feedback device. Average speed was reduced by 4.4 mph immediately after implementation. After 3 weeks, the average speed was reduced by an additional 2.3 mph, although still in excess of the posted speed limit. Paired t-test statistics were computed to confirm that these reductions in operating speeds were statistically significant at the 95 percent confidence level. The test results indicated that all reductions in speeds were statistically significant.

2.2 Use of Dynamic Speed Display Signs to Communicate Speeds

The performance of speed monitoring display (SMD) devices located within a work zone along Interstate 80 in Nebraska was evaluated over a 5-week period (Pesti and McCoy, 2001). A speed limit sign, displaying the regulatory speed within the work zone, was located on top of the SMD (e.g., see Figure 1). Three SMDs were placed within a section of the highway between a median crossover and a right-lane closure work area. The first device was located on the left side of the road, 1,150 ft downstream of the median crossover. The second device, also on the left side of the road, was placed where the highest mean speed was observed based on a speed profile plot. The second device was located approximately 6,500 ft downstream of the first device and 5,000 ft in advance of the lane closure. The third SMD was located on the right side, immediately upstream of the lane closure. The layout of the data collection site is shown in Figure 2.

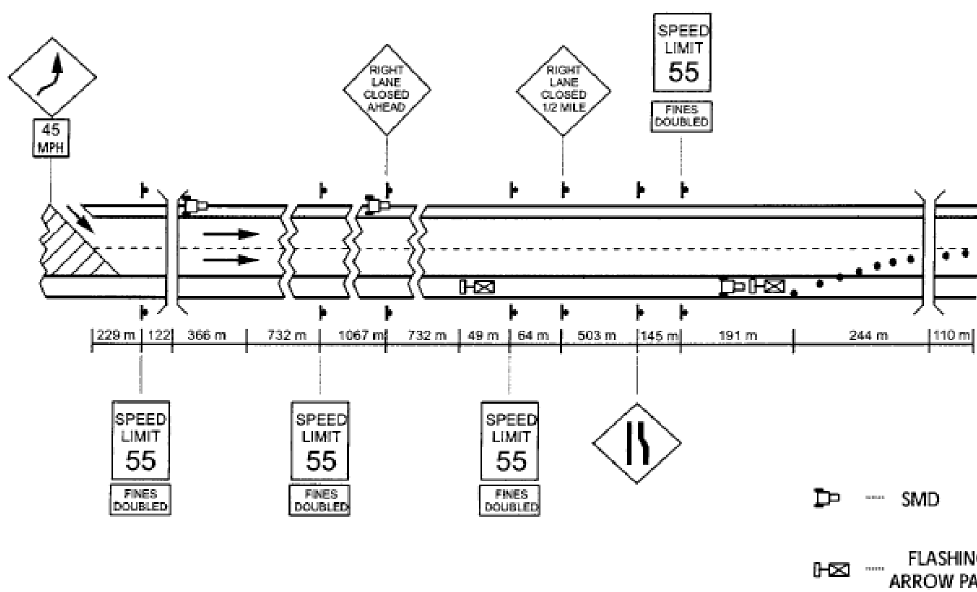

Figure 2. Speed Monitoring Display Work Zone Site Layout (Pesti and McCoy, 2001).

Before-data were collected 4 weeks before installation of the devices. During-data were recorded once each week for 5 weeks after the SMDs were in place. Speed data were also recorded 1 week after removal of the devices. Speed data were observed upstream of the first SMD and immediately downstream of each of the three SMDs. All mean speeds and 85th percentile speeds in the 5-week after period were less than the before period at all data collection locations. The overall reduction in mean speeds was approximately 3 to 4 mph and 85th percentile speeds were reduced between 2 and 7 mph. The speed reductions got progressively smaller as vehicles passed the first SMD. Speed standard deviations were also significantly lower during the after period. After removal of the devices, mean and 85th percentile operating speeds increased but remained less than the before period.

Ullman and Rose (2005) evaluated the effectiveness of dynamic display signs along various sections of highway that required lower operating speeds than their upstream sections. Included was one school zone, two school zone approaches, two signalized intersection approaches on high-speed roads, and two approaches to sharp horizontal curves. Data collected before installation of the devices were compared to data collected at two time periods after installation. The after periods occurred 2 to 4 weeks and 2 to 4 months after installation of the devices. The results indicated that all mean speeds of vehicles during the short term after the installation period (2 to 4 weeks) were significantly lower than their corresponding before-data, except for trucks entering a sharp curve. When compared to the data collected 2 to 4 months after installation, the results were mixed; some sites experienced even lower speeds than the previous two time periods, while speeds at other sites were higher than the short-term period but still lower than in the before condition. This is illustrated in Table 2. In Table 2, site 1 is the school zone, sites 2 and 3 are the advance warning area approaching a school zone, sites 4 and 5 are the signalized intersection approaches, and sites 6 and 7 are the sharp horizontal curve locations. Speeds of trucks at sites that included a sharp horizontal curve were significantly higher in the long-after period than in the before condition. The proportion of vehicles speeding during these three time periods was also calculated and the results were also mixed; some percentages decreased in both the short- and long-term after periods, while some sites that experienced reductions in speeding vehicles in the short-term after period later experienced an increase to even higher values than the before period.

The authors also performed regression analyses to explain the relationship between speeds upstream of the dynamic speed display sign locations and at the sign location for both after installation periods. The results indicated that at several sites, those vehicles traveling at high speeds slowed down more than those vehicles traveling at lower speeds during the short-term period after installation of the devices. When estimated using the long-term after period installation data (2 to 4 months), the regressions indicated that drivers get accustomed to the display signs. The authors concluded that dynamic speed display signs are effective in school zones; in other traffic conditions, however, these devices are able to obtain reductions of operating speeds (1 to 4 mph), but the magnitude of the speed reductions is small.

The School Safety Act in South Korea restricted speed limits on roadways near schools to 20 mph. Following enactment of this legislation, the frequency of accidents increased. In response to this development, Lee et al. (2007) evaluated the effectiveness of speed-monitoring displays in reducing speeds. Speed data were collected at seven locations before, 2 weeks after, and 1 year after implementation of the SMD devices. Speed measurements were taken adjacent to the posted speed limit sign and the SMD, which was located approximately 550 ft downstream of the posted speed limit sign. An additional speed measurement location was located outside the limits of the study site to determine the amount of speed variability not related to the SMD device. Speed profiles indicated that, 2 weeks after SMD installation, speed reductions increased as drivers approached the device. The mean speed next to the SMD decreased from 27.9 mph in the before period to 23.3 mph 2 weeks after implementation. The results of the long-term study suggested that SMD effectiveness diminished over time; the average speed at the SMD location 1 year after implementation was 24.9 mph, a 3 mph difference when compared to the before period. These speed reductions were statistically significant. Additionally, the proportion of vehicles traveling less than 25 mph increased from 28.6 percent in the before period to 64.4 percent in the short-term after period. During the long-term after period, 57.1 percent of drivers traveled less than 25 mph at the study locations. In the before period, 26.5 percent of vehicles traveled faster than 30 mph while in the short-term after period, only 9.9 percent of vehicles exceeded 30 mph. During the long-term after period, only 5.4 percent of vehicles traveled in excess of 30 mph. It was concluded that SMD devices are effective in reducing speeds for a period of 12 months.

Table 2. Average Speeds and Speed Differences in Texas Study (Ullman and Rose, 2005).

Site	**Average Speed (mph)**			**Speed Difference, mph (Before – After)**	
	Before	**Short-term After**	**Long-term After**	**Short-term**	**Long-term**
1 (Active)	44.5	35.3	35.7	9.2	8.8
1 (Inactive)	51.9	48.3	49.0	3.6	2.9
2	55.2	51.8	53.8	3.4	1.4
3	47.7	45.1	46.3	2.6	1.4
4	57.5	54.1	57.7	3.4	-0.2
5	45.3	41.7	41.3	3.6	4.0
6 (Autos)	37.1	33.6	37.1	3.5	0.0
6 (Trucks)	30.0	30.6	35.2	-0.6	-5.2
7 (Autos)	35.3	33.2	32.9	2.1	2.4
7 (Trucks)	31.5	29.2	32.8	2.3	-1.3

Sandberg et al. (2006) evaluated the long-term effectiveness of dynamic speed monitoring display (DSMD) signs along two-lane rural highways in Minnesota. These sections transitioned from high- to low-speed operations as the roadway passed from a rural area through an urban setting. The before-during study included four experimental sites and one control site. The required speed reductions varied from site to site, and these were indicated by regulatory speed limit signs. Speed data were recorded at a location between 1/3 and 1/2 mile upstream of the DSMD and next to the DSMD. The data collection time periods were before DSMD implementation, and 1 week, 2 months, 7 months, and 1 year during implementation. No post-implementation period was included in the experiment to evaluate if speeds increased after removing the DSMD from the site. Average speeds, along with 50^{th}, 85^{th}, and 95^{th} percentile speeds, and the 10-mph pace were analyzed using various statistical methods (ANOVA, z-tests, t-tests, and odds ratios). The results indicated that all percentile speeds as well as the 10 mph pace were reduced at all experimental locations. The 50^{th}, 85^{th}, and 95^{th} percentile speeds decreased by 6.3, 6.9, and 7 mph, respectively, and these were consistent throughout the entire 1-year study period. The authors concluded that DSMD signs combined with a speed limit sign have “a long-term positive effect on driver speed” in transition zones.

2.3 Use of Variable Message Signs to Communicate Travel Speeds

Rämä (2001) studied the effectiveness of a variable message sign (VMS) used in combination with a dynamic SLIPPERY WHEN WET sign during adverse weather conditions at three locations in Finland. In Finland, posted speed limits are reduced during the winter season. Highways with posted speed limits of 70 mph are reduced to 60 mph and those with speed limits of 60 mph are reduced to 50 mph. Although the VMS was not used to communicate operating speeds to drivers, messages were displayed to warn drivers of the precautions necessary during winter travel. The following messages were displayed during various phases of the study, depending on the weather conditions: slippery road conditions, minimum headway displays, temperature displays, and posted speed limits. The slippery road condition sign, which was either off, in steady mode, or flashing, was studied in combination with a minimum headway sign during one phase. The minimum headway sign was always on and would display recommended headways depending on vehicle length, speed, and road conditions. A before-after study with control site design was used for the evaluation. The results indicated that the slippery road condition sign, in steady mode and in combination with the minimum headway sign, decreased the mean speed of free-flow vehicles at two of the experimental sites by an average of 0.7 mph. In flashing mode, the same two sites had a mean speed reduction of 1.2 mph. At the third location, mean speeds increased 1.4 and 0.5 mph for steady and flashing mode, respectively. All these results were statistically significant and were more substantial at night.

Additionally, Rämä (2001) tested the effect of the VMS devices on speed standard deviation; the results indicated that the VMS did not have a significant effect on speed standard deviation. When considering headways, the proportion of short headways (less than 0.5 seconds out of all headways of 5 seconds or less) significantly decreased at one of the experimental sites; at another site there were no significant changes in headways; while at the last site, there was a slight decrease in the proportion of short headways.

Ulfarsson et al. (2002, 2005) evaluated the effects of VMS and speed limit signs on mean speed and speed standard deviation during adverse weather conditions along Interstate 90 in Washington State. The VMS devices displayed variable speed limits depending on the road conditions. Speed data were collected at two locations—within the influence of the VMS and at a location downstream of the VMS—to test if the effect of the device lasted "outside the immediate area." A simultaneous equations approach (using 3SLS) was used to account for the endogeneity of mean speed and speed deviation. Speed data were collected in both directions of travel to determine if the VMS had a different effect based on the roadway profile (i.e., one direction of travel was on an upgrade while the other was on a downgrade). Since the VMS devices were turned on during adverse weather conditions, it was necessary to isolate the effects of the device. The results indicated that the use of the VMS significantly reduced mean speeds in both directions of travel at the VMS location; reductions in speed deviation were only obtained in the upgrade direction. The authors indicated that "adverse weather conditions may affect the uphill speeds more than downhill speeds. The beneficial effect of the VMS device on speed deviation does therefore seem to depend on speed and speed deviation." It was concluded that adverse weather conditions resulted in lower mean operating speeds with higher speed deviations. In good weather, mean speeds were higher while speed deviations decreased when compared to the adverse weather condition.

Ulfarsson et al. (2002, 2005) concluded that VMSs are able to significantly reduce mean speed. For speed deviations, the authors suggested that when road conditions cause high speeds and lower speed deviations, these devices will significantly reduce mean speeds but increase speed deviation. On the contrary, where ambient weather conditions produce lower speeds but higher speed deviations, the devices are able to significantly reduce both mean speed and speed deviation. The authors recommended that VMS only be used during some adverse weather conditions. For example, in situations where drivers believe that the road conditions are improving downstream, it was concluded that the VMS devices may reduce mean speed but will increase speed deviations. These increased speed deviations may be associated with increased accident frequencies. Results also indicated that drivers, after reducing their speed due to the VMS, accepted these lower speeds and did not increase their speed at the location downstream of the VMS.

2.4 Summary

Dynamic speed management methods have been used in a variety of settings, including work zones, school zones, high-speed intersection approaches, in advance of horizontal curves, and along transition zones. The results of past research suggest that dynamic speed management methods are effective in reducing vehicle operating speeds in the short-term (i.e., immediately after implementation of the device). In general, past research suggests that dynamic speed management methods also have long-term benefits, even after removal of the speed communication device. In some cases, however, vehicle operating speeds approached those observed prior to implementation of the device at a site. The most common evaluation methodology used in past research was a before-after observational study where free-flow vehicle speeds were observed prior to implementation of a speed management strategy and then speeds were observed again while the device was in place. Table 3 is a tabular summary of past research related to the use of dynamic speed management methods. It contains the authors, a brief description of the sites included in the speed evaluation, and a short narrative discussion of the findings from the cited study. It is important to note that past research efforts have evaluated a variety of speed monitoring display signs; however, these past studies have focused on work zones and on highways that experience highly variable weather conditions. Little past research has focused on evaluating speed monitoring display signs at locations along rural highways that transition from high- to low-speed operations.

Table 3. Summary of Dynamic Speed Management Studies.

Authors	**Site Description**	**Conclusions**
Richards and Dudek	Arterial and freeway work zones	Speed reductions related to CMS were less than 10 mph.
McCoy et al.	Work zone along Interstate 90 in South Dakota	SMD were associated with mean speed reductions.
Garber and Patel	Work zones along seven Interstates in Virginia	Mean speed reductions were 15.25 mph; YOU ARE SPEEDING SLOW DOWN message was the most influential.
Garber and Srinivasan	Work zones in primary highways and Interstates in Virginia	Mean speed reductions were between 5.29 and 7.09 mph.
Dixon and Wang	Work zones in Georgia	Immediate speed reductions were between 5 and 7 mph.
Chitturi and Benekohal	Along Interstate 70 in Illinois	Immediate speed reduction was 4.4 mph; after 3 weeks there was an additional speed reduction of 2.3 mph.
Pesti and McCoy	Work zone along Interstate 80 in Nebraska	Mean speeds were reduced by 3.4 mph.
Ullman and Rose	School zone, school zone approaches, approaching signalized intersections and sharp horizontal curves in Texas	Results were mixed; greatest reduction was at school zone site (8.8 and 9.2 mph) while other sites had speed reductions ranging from 1.4 to 4 mph. Some sites experienced increase in mean speeds.
Lee et al.	School zone in South Korea	Immediate speed reduction was 4.6 mph; after 1 year the mean speed reduction was 3 mph.
Sandberg et al.	Transition zone along two-lane rural highway in Minnesota	85th percentile speeds decreased by 6.9 mph and were consistent over a year.
Rämä	Highways in Finland during winter season	Greatest reduction in mean speeds for suggested headways was 1.2 mph.
Ulfarsson et al.	During adverse weather conditions on Interstate 90, Washington State	Both mean speeds and speed deviations were reduced.

3.0 SITE SELECTION AND DATA COLLECTION

This section of the report describes the site selection process and the procedure to collect data at the study sites, including the placement of the speed minders at each site. The study consists of collecting operating speed data from free-flow passenger cars before, during, and after implementation of speed minders. Data were collected at various locations in PennDOT Engineering Districts 2-0 and 10-0. Speed data were collected during daytime periods only and during weekday, non-peak travel periods, and under dry pavement conditions.

3.1 Site Selection

A total of 17 study sites were identified to test the effectiveness of speed minders on rural highways in Pennsylvania. These locations were distributed between PennDOT Engineering Districts 2-0 and 10-0. Seven sites, located in District 2-0, were identified jointly between the authors and District traffic engineering unit staff. These sites were all selected because of the change in posted speed limit from high to low speed. Each of these sites passes through a rural community. All of the sites in District 2-0 are referred to as “transition zones” because of the change in the regulatory speed limit. The remaining 10 sites were located in District 10-0, and these were identified by the traffic engineering unit in response to concerns expressed by residents about speeding vehicles near the proposed data collection locations. These sites cover a wide range of highway characteristics, such as the presence of a two-way left-turn lane, high- to low-speed transition zones, changes in land use, and other roadway cross-section changes. Table 4 lists the 17 study sites, including the segment location and posted speed limit.

3.2 Speed Minder Locations

Staff from PennDOT’s Engineering District 2-0 and 10-0 traffic engineering units was responsible for determining the location of the speed minders at each study site. Each speed minder location was designated prior to beginning field data collection efforts at that particular site. Of particular interest were the transition zone locations. Enforcement cannot occur within the area 500 ft downstream of a static sign that is intended to regulate a speed limit that differs from an adjacent, upstream speed zone. At each of the transition zone locations noted in Table 4, the speed minder was located at least 500 ft downstream of the speed limit sign used to designate the lower speed when compared to the adjacent speed zone. This criterion applies to sites 1 through 7, 10, 12, 13, 15, 16, and 17 in Table 4. Figure 3 shows a typical transition zone along a rural two-lane highway and the proposed speed minder location. PennDOT was responsible for informing all municipalities of the proposed speed minder locations. Additionally, PennDOT was responsible for notifying state and local enforcement personnel of the proposed speed minder locations and data collection time periods. No speed enforcement was in place at the data collection locations during the before, during, or after data collection periods.

Table 4. Study Site Locations.

Site ID	District	County	State Route	Segment	Posted Speed Limit
1	2-0	Centre	550 NB	0520-0540	55→40*
2	2-0	Centre	192 EB	0270-0290	55→35*
3	2-0	Centre	192 EB	0210-0220	55→40*
4	2-0	Clearfield	53 NB	0480-0490	45→25*
5	2-0	Centre	3040 NB	0360-0370	55→35*
6	2-0	Clearfield	453 NB	0390-0410	45→25*
7	2-0	Clearfield	879 EB	0100-0110	45→25*
8	10-0	Indiana	56 EB	0550-0560	55
9	10-0	Indiana	422 WB	0490-0510	55
10	10-0	Indiana	553WB	0160-0170	55→35*
11	10-0	Indiana	4422 EB	0020-0040	45
12	10-0	Indiana	3035 NB	0010-0030	55→35*
13	10-0	Indiana	110 EB	0070-0080	55→35*
14	10-0	Armstrong	422 EB	0310-0320	55
15	10-0	Butler	356 NB	0110	55→40*
16	10-0	Armstrong	66 SB	0040	55→40*
17	10-0	Jefferson	322 WB	0020-0030	55→35*

Notes:
* indicates that the study segment is a transition zone.
NB: northbound
SB: southbound
EB: eastbound
WB: westbound

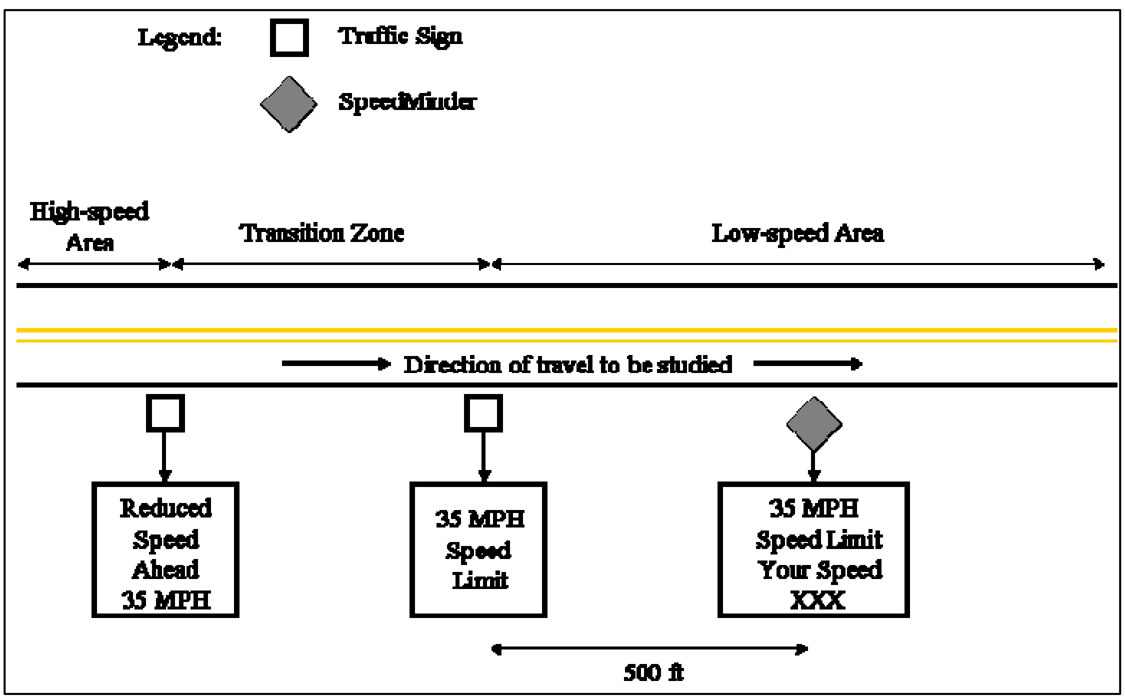

Figure 3. Speed Minder Location at a Typical Transition Zone.

3.3 Data Collection Equipment and Locations

Speed data were collected using Nu-Metrics Hi-Star sensors. The Hi-Star sensors use vehicle magnetic imaging technology to record vehicle count, speed, headway, time, pavement temperature, pavement condition (dry or wet), and vehicle length. These sensors are non-intrusive, thus eliminating the possibility of vehicles adjusting their speeds due to visible equipment and human observers. The dimensions of the sensor are 6.5 inches by 5.5 inches with a thickness of 0.625 inches. The sensor is placed in the center of the travel lane and when a vehicle passes over it, changes in the magnetic field are captured by the sensor. A rubber cover is used to protect the sensor and at the same time reduce its conspicuity; this cover blends in with the pavement, thus minimizing visibility. The Highway Data Management (HDM) software was used to download the data from the sensors into Microsoft Excel spreadsheets for efficient data management.

To evaluate the effectiveness of the speed minders, speed data were collected by placing the Hi-Star sensors at three different points at each study site. These locations are as follows: sensor #1, between 0.33 and 0.5 miles upstream of the speed minder location, where operating speeds can be measured without influence by the speed minder (i.e., speed minder is not visible to drivers); sensor #2, next to the speed minder, in order to record any immediate speed reductions due to implementation of the device; and sensor #3, 500 ft downstream of the speed minder implementation location, to record any additional speed reductions attributable to the presence of the device. Figure 4 shows the location of the Hi-Star sensors along a study site in relation to the speed minder location.

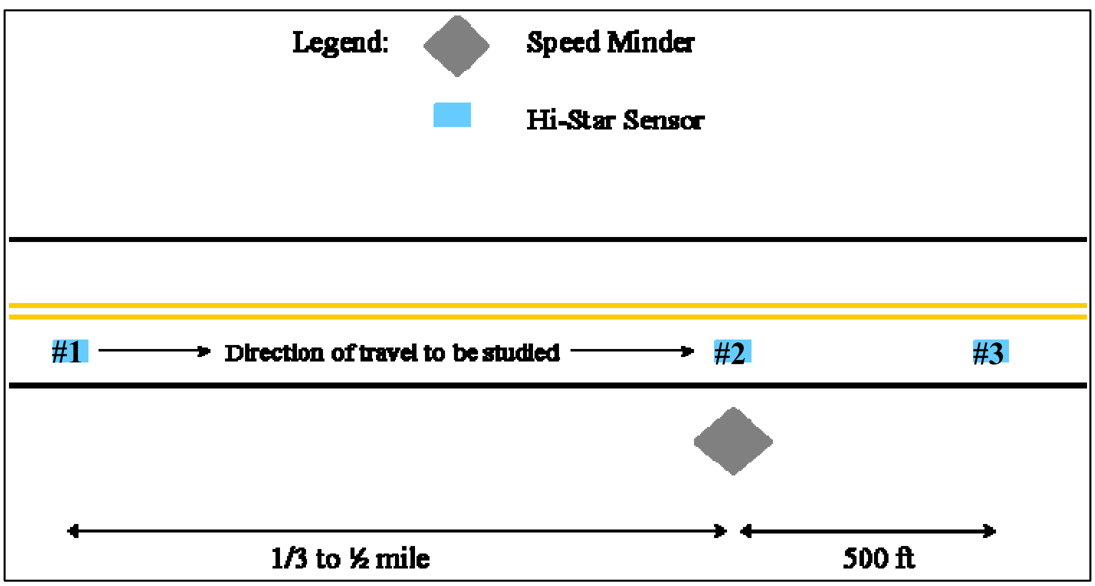

Figure 4. Location of Hi-Star Sensors Relative to Speed Minder Location.

3.4 Sample Size Determination

The process to determine the sample size when mean speed is the variable of interest is based on the following equation (ITE, 1994):

$$N = (S\frac{K}{E})^2 \tag{1}$$

where: N = minimum number of measured speeds;
S = estimated sample standard deviation, mph;
K = constant corresponding to the desired confidence level; and
E = permitted error in the average speed estimate, mph.

To obtain a range of possible sample sizes, multiple values for the confidence level, *K*, were considered. The values correspond to confidence levels of 90, 95, and 99 percent. The permitted error in the average speed estimate, *E*, has been included as a conservative value of ±1 percent. The estimate of sample standard deviation, *S*, is a function of traffic area and highway type. The input value of 5.3 is representative of a rural, two-lane highway (ITE, 1994). The resulting sample size estimates for the proposed confidence interval, permitted error, and standard deviation estimates are summarized in Table 5.

Table 5. Values for Sample-Size Determination.

Confidence Interval	K	N
90%	1.64	76
95%	1.96	108
99%	2.58	187

As shown in Table 5, the estimated sample size for the 95th-percentile confidence interval is 108 samples.

3.5 Data Collection Periods and Durations

Speed data were collected on weekdays only and during daytime, non-peak hours in order to increase the likelihood of obtaining free-flow vehicles during the data collection period. Based on previous research, free-flow vehicles were identified as those vehicles traveling with a minimum headway of 5 seconds (Polus et al., 2000 and Fitzpatrick et al., 2005). At each study site, data were collected during favorable driving conditions: clear weather with normal visibility and no precipitation (i.e., rain, snow, or fog) or standing water from an earlier rain or melting snow. These requirements ensured that drivers were selecting their operating speeds based solely on the environmental conditions at each site; during and after speed minder device implementation, any changes in operating speeds could then be attributed to the speed minder device. Data collection at each study site took place for a duration that would meet the minimum sample size requirements, or until the battery life of the on-pavement sensors was depleted. It should be noted that collecting the minimum sample size was dependent on the traffic characteristics at each study site, particularly the traffic volume, time headway, and number of heavy vehicles in the traffic stream.

4.0 ANALYSIS METHODOLOGY

The study methodology used in the present experiment was an observational before-during-after study. The "before" data were collected before implementation of the speed minder devices. At all 17 sites, the "during" period represents a data collection time period while the speed minders were in place and activated. The "during" data collection period took place during a time period that was less than 1 week after the speed minder was placed and activated at each site. A second "during" data collection period took place during the second week of speed minder presence at four locations (SR 110 EB in Indiana County; SR 4422 EB in Indiana County; SR 53 NB in Clearfield County; and SR 3040 NB in Centre County). This second "during" period was intended to determine if the speed minders maintain their effectiveness while activated for periods longer than 1 week. The "after" data collection period took place at the study sites within 1 week after the speed minder device was deactivated and removed. Similarly to the second "during" period, a second "after" data collection period took place during the second week after the speed minder was removed at the same four sites to determine longer-term effects.

Prior to the start of the data analysis, all raw data from the study sites were screened to exclude all vehicles that were not passenger cars and that were not considered free-flow vehicles, as described previously. All vehicles were "tracked" through the study site, so the same vehicles in the analysis were observed at each of the three sensor locations within a segment. Data points considered outliers were carefully evaluated to determine if they should be eliminated or included in the analysis. Examples of outliers include vehicles traveling at very low speeds wishing to enter or exit nearby driveways or turn onto an intersecting roadway.

After data screening, mean and 85th-percentile operating speeds, speed deviation, and percentage of vehicles exceeding the posted speed limit were calculated at each sensor location for all sites and all data collection periods. Differences between the mean speeds before, during, and after speed minder activation were computed. An independent samples t-test was then used to determine if the difference in mean speeds was statistically significant. Statistically significant changes in the mean operating speeds indicate that the observed speeds were different in the two time periods being compared. The t-statistic is commonly used to test the hypothesis of differences in population parameters (Washington et al., 2003). In this study the null and alternative hypotheses for testing the differences in two mean speed measures, μ_1 and μ_2, are:

- Null Hypothesis (H_0): there has not been a change in mean speed as a result of speed minder implementation/removal, or H_0: $\mu_1 - \mu_2 = 0$

- Alternative Hypothesis (H_a): There has been a change in mean speed as a result of speed minder implementation/removal, or H_a: $\mu_1 - \mu_2 \neq 0$.

The t-statistic is given by:

$$t = \frac{(\overline{X}_B - \overline{X}_A)}{\sqrt{\frac{s_B^2}{n_B} + \frac{s_A^2}{n_A}}} \qquad (2)$$

where:

$\overline{X}_B, \overline{X}_A$ = mean speed for the before and after periods;
s_B, s_A = standard error of speed for the before and after periods; and
n_B, n_A = sample size in before and after periods.

In equation 2 above, the "during" period data can be substituted for either the "before" or "after" periods noted.

The degrees of freedom (df) for the independent samples t-test is $n_A + n_B - 2$. The critical value when $\alpha = 0.05$ for a two-tail test is $\pm$ 1.96. The null hypothesis is rejected when the computed t-test exceeds the critical value, thus concluding that the mean speeds being compared differ between the two collection periods being considered, based on the sample size. An alternative method to determine the statistical significance of speed minders on mean speed is the p-value associated with the t-statistic. A low p-value (i.e., less than or equal to 0.05) indicates a high probability that the presence or absence of the speed minder influenced mean speeds between two data collection periods. The t-statistic and p-value were computed for each pair of collection periods at each study site.

In addition to the t-test, the percentage of vehicles exceeding the posted speed limit at the speed minder location was calculated and compared between data collection periods. The percentage of speeding vehicles, P_S, is computed as

$$P_S = \frac{x}{n} \times 100 \qquad (3)$$

where:

x = number of vehicles exceeding the posted speed limit; and
n = the total number of free-flow vehicles in the sample.

By comparing the number of vehicles exceeding the posted speed limit between two data collection periods, it can be determined if the speed minder devices are associated with a reduction in the proportion of posted speed limit violations. The percent reduction of speeding vehicles, $\%R_S$, between two periods, 1 and 2, at the speed minder location was computed as follows:

$$\%R_S = \frac{P_{S1} - P_{S2}}{P_{S1}} \times 100 \quad (4)$$

where:

P_{S1} = the proportion of vehicles speeding during the first data collection period; and
P_{S2} = the proportion of vehicles speeding during the second data collection period.

In order to determine if the reduction in vehicles exceeding the speed limit at the speed minder location is statistically significant, a Z-test for independent samples was computed. The null and alternative hypotheses for the test are:

- Null Hypothesis (H_0): There is no difference between the two sample proportions, or H_0: $P_{S1} - P_{S2} = 0$
- Alternative Hypothesis (H_a): There is a difference between the two sample proportions, H_0: $P_{S1} - P_{S2} \neq 0$.

The Z-statistic used to determine the statistical difference between the two proportions is as follows:

$$Z = \frac{P_{S1} - P_{S2}}{\sqrt{P(1-P)\left(\frac{1}{n_1} - \frac{1}{n_2}\right)}} \quad (5)$$

where P_{S1} and P_{S2} are the sample proportions from equation 3, n_1 and n_2 are sample sizes for the corresponding proportions being considered, and P is the combined proportion in both samples, computed as follows:

$$P = \frac{x_1 + x_2}{n_1 + n_2} \quad (6)$$

Similar to the t-statistic, the Z-statistic is associated with a p-value. A p-value of 0.05 or less results in rejecting the null hypothesis and concluding that, based on the sample size, the speed minders are effective in reducing the number of vehicles exceeding the speed limit at the 95 percent confidence level.

5.0 ANALYSIS RESULTS

This section of the report presents the analysis results based on the methodology described in section 4.0. The first part of this section contains results from each individual study site where speeds were compared before, during, and after speed minder implementation at each sensor location. The second part of this section contains speed differential results from the analysis where speed changes between successive sensors were computed and compared before, during, and after speed minder implementation.

5.1 Individual Point Speed Site Analysis Results

The results from each individual site, based on a point speed analysis for each sensor location, are presented in this section. Because driver behavior was similar at many of the study sites, the results are synthesized in this section. Specific details of each individual site are contained in Appendix A of this report. Appendix A contains descriptive statistics of the data collected at each sensor location, for each data collection time period, at each study site. Additionally, Appendix A contains results of all statistical tests described in section 4.0 along with speed profile plots for each individual site analysis. This section contains a discussion of the expected results of the analysis, a summary of all statistical tests performed to determine the effects of the speed minders, and several example graphical illustrations of the speed profiles that were developed for each site. Please refer to Figure 4 on page 15 for a graphical illustration of the placement of sensors #1, #2, and #3 in relation to the speed minder device at each study site.

It was expected that the before, during, and after period speeds would be nearly equal at sensor #1 (upstream of the proposed speed minder implementation point) at all sites because this point served as a control point where drivers would not see the speed minder device. If this result was proven by the statistical analysis (independent samples t-test of mean vehicle speeds), then it is reasonable to conclude that the effect of the speed minder could be captured by simply computing the difference in mean speeds at the speed minder implementation point (sensor #2). If this was not the case, an alternative analysis would be required, as discussed further in section 5.3.

At the sites where the posted speed limit changed (transition zones), it was expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location (sensor #1) during the before period because of the regulatory speed limit change. At locations where the posted speed limit did not change, it was expected that the mean speeds at the speed minder location (sensor #2) would be nearly equal to the mean speeds at the upstream location (sensor #1) during the before data collection period. During the time period that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period at all study sites. At the downstream location (sensor #3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2 at all study sites. If the observed mean speeds were higher after the speed minder location, then motorists likely perceived the speed minder as a form of enforcement and, after passing by the device, accelerated to a speed they considered appropriate for the operating environment. If motorists continued to decelerate or maintained a constant speed, it was hypothesized that the speed minder had the desirable effect of reducing speeds in the transition zone to a level near the regulatory speed. These expected results are illustrated graphically in Figures 5 and 6. Figure 5 is an illustration of the expected speed profile at study site locations that contained a posted speed limit change and Figure 6 is an illustration at study sites that did not contain a posted speed limit change.

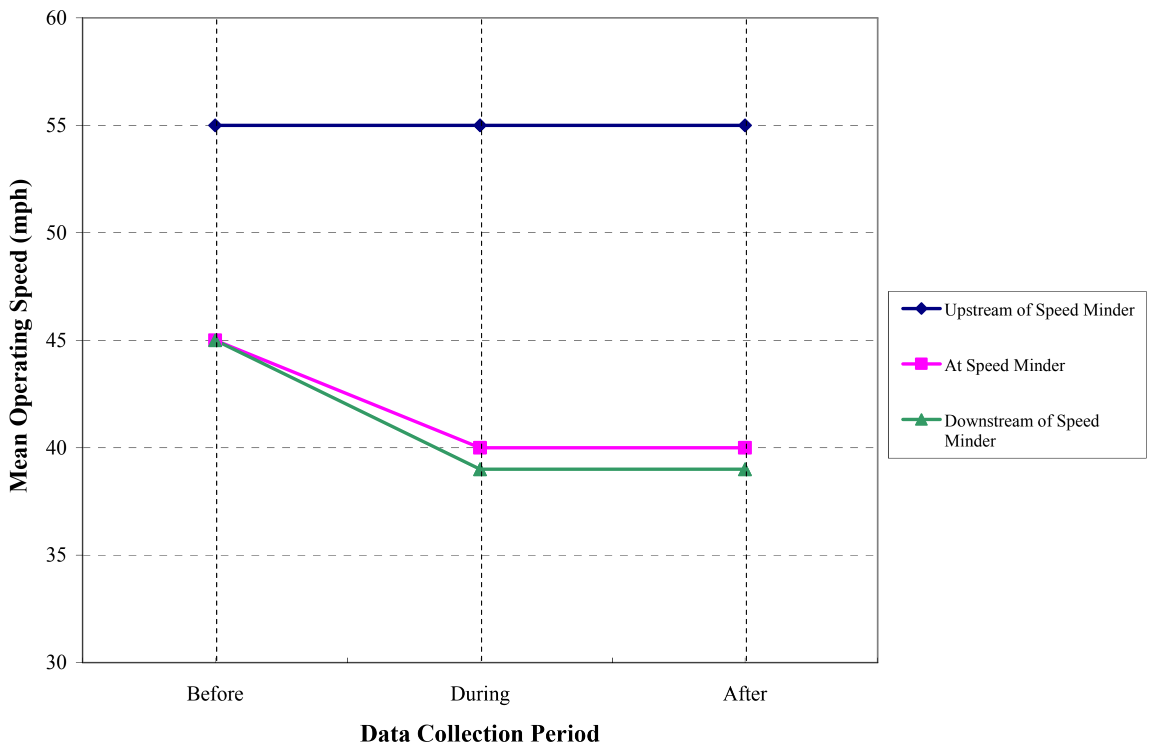

Figure 5. Anticipated Speed Profile at Sites with Speed Limit Reduction (Transition Zones).

As shown in Figure 5, the mean speed is constant at the upstream data collection point (sensor #1) in the before, during, and after periods. At the speed minder data collection point (sensor #2), the mean speed is lower in the before period when compared to the upstream data collection point (sensor #1). The mean speed at the speed minder data collection point in the during period is lower than the mean speed in the before period – this indicates that the speed minder did affect (i.e., decrease) mean operating speeds. The mean operating speed at the speed minder data collection point is the same in the after period as in the during period, indicating that the speed reduction effects observed when the speed minder was in place remained constant after the speed minder was removed from the site. The mean speed at the downstream data collection point (sensor #3) is intended to be similar to the speed minder location (sensor #2), indicating that the speed reduction observed at this location during and after speed minder implementation was the same as at the speed minder data collection point.

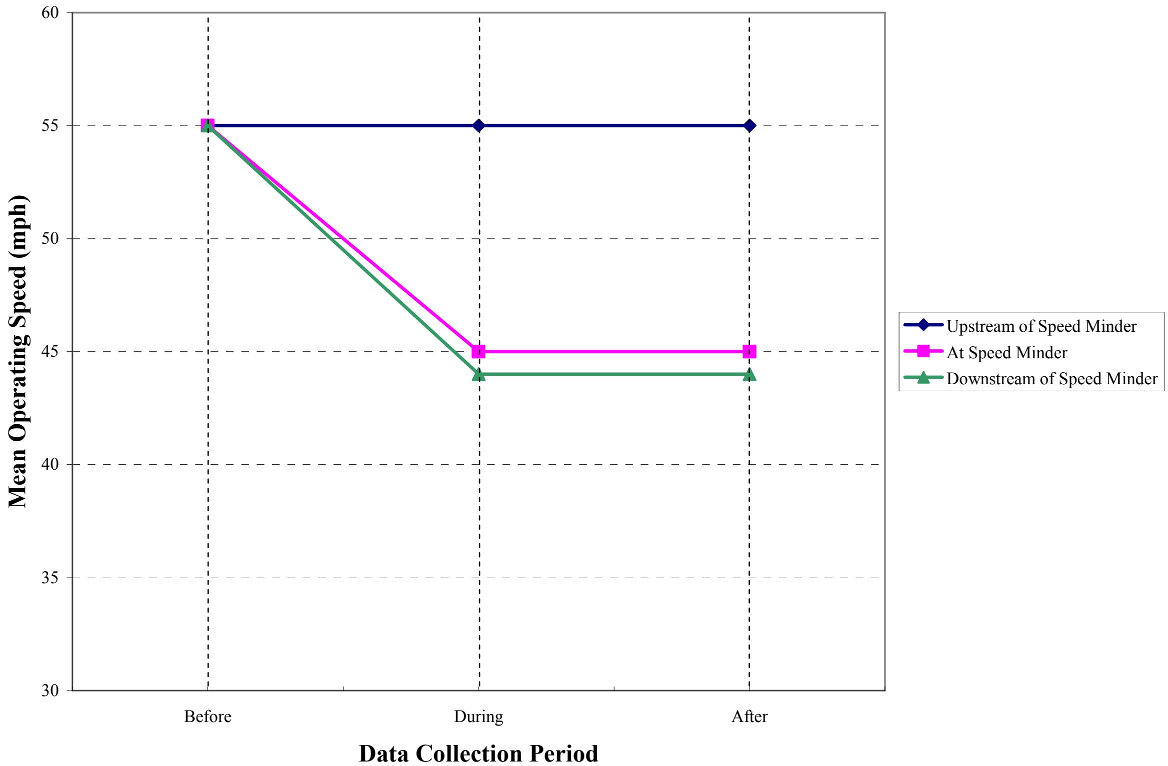

Figure 6. Anticipated Speed Profile at Sites with No Speed Limit Change.

As shown in Figure 6, the mean speed is constant at the upstream data collection point (sensor #1) in the before, during, and after periods. At the speed minder data collection point (sensor #2), the mean speed is equal in the before period when compared to the upstream data collection point (sensor #1) because no posted speed limit change occurs at the site. The mean speed at the speed minder data collection point in the during period is lower than the mean speed in the before period – this indicates that the speed minder did effect (i.e., decrease) mean operating speeds. The mean operating speed at the speed minder data collection point is the same in the after period as in the during period, indicating that the speed reduction effects observed when the speed minder was in place remained constant after the speed minder was removed from the site. The mean speed at the downstream data collection point (sensor #3) is intended to be similar to the speed minder location (sensor #2), indicating that the speed observed at this location before, during, and after speed minder implementation was the same as at the speed minder data collection point.

Table 6 contains the independent samples t-test comparison of mean operating speeds before, during, and after speed minder implementation for all data collection points at all study sites.

Table 6. Statistical Tests of Mean Speed Differences at All Study Sites.

Site	Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
SR 550[a]	1	Before – During	53.11	56.01	-4.16	0.000
		During - After	56.01	53.56	3.59	0.000
	2	Before – During	43.99	36.34	11.20	0.000
		During - After	36.34	42.46	-9.70	0.000
	3	Before – During	39.81	36.15	5.48	0.000
		During - After	36.15	39.09	-3.86	0.000
SR 192[a] Segments 0270-0290	1	Before – During	55.43	55.42	0.01	0.991
		During - After	55.42	56.57	-1.20	0.230
	2	Before – During	48.85	41.18	8.21	0.000
		During - After	41.18	50.38	-9.48	0.000
	3	Before – During	50.33	40.65	11.20	0.000
		During - After	40.65	48.96	-9.70	0.000
SR 192[a] Segments 0210-0220	1	Before – During	55.11	60.83	-4.59	0.000
		During - After	60.83	60.60	0.20	0.840
	2	Before – During	42.87	36.65	4.48	0.000
		During - After	36.65	44.77	-6.64	0.000
	3	Before – During	45.85	42.42	2.86	0.005
		During - After	42.42	46.21	-3.85	0.000
SR 53[a, b]	1	Before – During 1	46.95	45.20	1.98	0.049
		During 1 – During 2	45.20	44.03	1.83	0.069
		During 2 – After 1	44.03	44.03	0.00	1.000
		After 1 – After 2	44.03	44.77	-1.29	0.198
	2	Before – During 1	36.68	29.27	8.84	0.000
		During 1 – During 2	29.27	29.72	-0.72	0.470
		During 2 – After 1	29.72	36.73	-13.07	0.000
		After 1 – After 2	36.73	36.36	0.66	0.513
	3	Before – During 1	32.54	29.86	3.39	0.001
		During 1 – During 2	29.86	30.25	-0.66	0.508
		During 2 – After 1	30.25	34.42	-8.70	0.000
		After 1 – After 2	34.42	33.66	1.50	0.134
SR 3040[a, b]	1	Before – During 1	57.71	53.67	3.15	0.002
		During 1 – During 2	53.67	55.06	-1.52	0.130
		During 2 – After 1	55.06	56.30	-1.42	0.156
		After 1 – After 2	56.30	54.35	2.17	0.032
	2	Before – During 1	43.96	35.63	6.52	0.000
		During 1 – During 2	35.63	35.48	0.18	0.858
		During 2 – After 1	35.48	40.93	-6.64	0.000
		After 1 – After 2	40.93	42.90	-1.96	0.051
	3	Before – During 1	43.35	37.03	4.94	0.000
		During 1 – During 2	37.03	35.98	1.40	0.163
		During 2 – After 1	35.98	39.58	-4.91	0.000
		After 1 – After 2	39.58	42.12	-2.58	0.011

[a] Sites where posted speed limit changed along data collection site (transition zones).
[b] Sites where speed minders were implemented for a period of two consecutive weeks.

Table 6. Statistical Tests of Mean Speed Differences at All Study Sites (con't).

Site	Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
SR 453[a]	1	Before – During	42.52	44.98	-2.15	0.033
		During - After	44.98	45.61	-0.66	0.510
	2	Before – During	29.06	26.34	3.35	0.001
		During - After	26.34	29.42	-4.30	0.000
	3	Before – During	28.63	28.05	0.87	0.383
		During - After	28.05	28.34	-0.44	0.659
SR 56	1	Before – During	46.96	43.81	1.87	0.064
		During - After	43.81	41.79	1.09	0.277
	2	Before – During	48.40	39.40	5.78	0.000
		During - After	39.40	41.03	-0.90	0.368
	3	Before – During	51.85	42.89	6.85	0.000
		During - After	42.89	42.93	-0.03	0.980
SR 422 Indiana Co.	1	Before – During	57.73	57.67	0.08	0.935
		During - After	57.67	59.29	-2.08	0.039
	2	Before – During	53.23	51.00	2.96	0.003
		During - After	51.00	53.67	-3.69	0.000
	3	Before – During	53.87	50.88	4.24	0.000
		During - After	50.88	53.71	-3.64	0.000
SR 553[a]	1	Before – During	48.00	48.53	-0.68	0.500
		During - After	48.53	48.47	0.08	0.934
	2	Before – During	47.26	39.35	9.61	0.000
		During - After	39.35	47.17	-11.32	0.000
	3	Before – During	46.81	40.42	7.97	0.000
		During - After	40.42	47.67	-10.56	0.000
SR 4422[b]	1	Before – During 1	46.63	46.01	0.80	0.424
		During 1 – During 2	46.01	50.92	-6.05	0.000
		During 2 – After 1	50.92	47.77	3.44	0.001
		After 1 – After 2	47.77	48.02	-0.29	0.772
	2	Before – During 1	50.79	46.53	5.19	0.000
		During 1 – During 2	46.53	46.26	0.40	0.689
		During 2 – After 1	46.26	49.70	-4.94	0.000
		After 1 – After 2	49.70	51.49	-2.55	0.011
	3	Before – During 1	49.94	46.33	4.80	0.000
		During 1 – During 2	46.33	45.69	0.98	0.326
		During 2 – After 1	45.69	47.92	-3.64	0.000
		After 1 – After 2	47.92	49.25	-2.16	0.032
SR 3035[a]	1	Before – During	39.56	37.65	1.65	0.101
		During - After	37.65	38.23	-0.55	0.583
	2	Before – During	36.42	31.79	6.76	0.000
		During - After	31.79	37.66	-7.99	0.000
	3	Before – During	36.54	33.59	3.99	0.000
		During - After	33.59	35.82	-3.23	0.001

[a] Sites where posted speed limit changed along data collection site (transition zones).
[b] Sites where speed minders were implemented for a period of two consecutive weeks.

Table 6. Statistical Tests of Mean Speed Differences at All Study Sites (con't).

Site	Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
SR 110[a, b]	1	Before – During 1	56.69	56.01	0.90	0.369
		During 1 – During 2	56.01	56.04	-0.04	0.972
		During 2 – After 1	56.04	55.12	1.04	0.299
		After 1 – After 2	55.12	56.22	-1.15	0.250
	2	Before – During 1	46.81	41.20	7.25	0.000
		During 1 – During 2	41.20	42.88	-2.01	0.045
		During 2 – After 1	42.88	46.73	-4.81	0.000
		After 1 – After 2	46.73	47.59	-1.01	0.314
	3	Before – During 1	52.40	44.71	10.19	0.000
		During 1 – During 2	44.71	44.12	0.82	0.411
		During 2 – After 1	44.12	48.64	-6.27	0.000
		After 1 – After 2	48.64	49.38	-0.86	0.391
SR 422 Armstrong Co.	1	Before – During	56.48	57.04	-0.67	0.504
		During - After	57.04	54.99	2.38	0.018
	2	Before – During	59.00	55.77	4.66	0.000
		During - After	55.77	58.68	-4.08	0.000
	3	Before – During	52.49	49.99	2.67	0.008
		During - After	49.99	52.04	-2.50	0.013
SR 356[a]	1	Before – During	51.35	52.53	-1.89	0.060
		During - After	52.53	52.01	0.96	0.336
	2	Before – During	49.16	43.64	9.28	0.000
		During - After	43.64	49.13	-9.84	0.000
	3	Before – During	48.21	44.66	5.26	0.000
		During - After	44.66	47.17	-3.84	0.000
SR 66[a]	1	Before – During	52.27	50.87	2.23	0.026
		During - After	50.87	49.21	2.68	0.008
	2	Before – During	42.46	38.91	6.06	0.000
		During - After	38.91	43.14	-7.27	0.000
	3	Before – During	41.89	38.66	5.03	0.000
		During - After	38.66	45.16	-10.03	0.000
SR 322[a]	1	Before – During	51.17	51.94	-1.02	0.311
		During - After	51.94	51.68	0.38	0.701
	2	Before – During	43.13	36.36	9.23	0.000
		During - After	36.36	44.42	-12.62	0.000
	3	Before – During	39.95	35.06	7.12	0.000
		During - After	35.06	41.39	-10.68	0.000

[a] Sites where posted speed limit changed along data collection site (transition zones).
[b] Sites where speed minders were implemented for a period of two consecutive weeks.

In Table 6, when the t-statistic exceeds 1.96 (p-value ≤ 0.05) there is a statistically significant difference in the mean operating speed for the two data collection time periods being compared. The anticipated effects of the speed minder when located along study sections where a posted speed limit change occurred (transition zones) are shown in Figure 5. For this ideal situation to occur, the p-values in Table 6 at sites denoted with a superscript *a* should generally be as follows:

- At sensor #1: before-during and during-after comparisons – p-value > 0.05.
- At sensor #2: before-during comparison – p-value ≤ 0.05.

- At sensor #2: during-after comparison – p-value > 0.05.
- At sensor #3: before-during comparison – p-value ≤ 0.05.
- At sensor #3: during-after comparison – p-value > 0.05.

None of the study site locations where a posted speed limit change was present exhibited the ideal or anticipated results; however, several sites exhibited many of the characteristics associated with the ideal scenario shown in Figure 5. The primary reason that the ideal scenario was not completely observed was because after the speed minders were removed from the site, the mean operating speeds increased to a level that was nearly identical to the before period mean operating speeds. Several interesting findings are of note:

- There was not a statistically significant difference in the mean operating speeds at the data collection point upstream of the speed minder location (sensor #1) during any of the data collection time periods at SR 192 (segments 0270-0290), SR 53, SR 553, SR 3035, SR 110, SR 356, and SR 322. This result was expected because this data collection point served as a control location where vehicle speeds were not expected to be different during any of the data collection time periods. At these 7 locations (of 13 where a speed limit change occurred), the effect of the speed minder could be determined by simply subtracting the mean operating speed in the before period from the mean operating speed in the during period. The range of speed reductions thus attributed to the speed minder at these 7 locations was 4.6 to 7.9 mph. The mean speed reduction attributed to the speed minders at these 7 locations was 6.5 mph.
- There was a statistically significant difference in the mean operating speeds at the data collection point upstream of the speed minder location (sensor #1) either between the before and during periods, or between the during and after periods at 6 of 13 sites where a speed limit change was present. To determine the true effect of the speed minder at these locations, the analysis presented in the next section of the report must be used.
- At all 13 locations where a speed limit change was present, the mean operating speed increased after the speed minders were removed from the site. This speed increase ranged from 3.1 to 9.2 mph. The average speed increase at these 13 locations was 6.0 mph.
- At 11 of the 13 locations where a speed limit change was present, the mean operating speed at the downstream data collection point (sensor #3) was statistically significant when comparing the before and during periods. The range of the speed reduction was 2.7 to 9.7 mph, with a mean of 5.0 mph. The speed at the downstream site was generally within 2.0 mph of the mean speeds observed at the speed minder data collection point (sensor #2). This suggests that once drivers pass the speed minder display, operating speeds generally remained constant.
- There were three speed reduction study site locations (SR 53, SR 3040, and SR 110) where the speed minders were deployed for two consecutive weeks. At each of these three locations, the mean operating speeds at the speed minder location were lower in the during period than before the speed minders were deployed.

During the second week of deployment, the speed reductions remained suggesting that the speed minders were effective over a period longer than one week.

The anticipated effects of the speed minder when located along study sections where the posted speed limit remained constant is shown in Figure 6. For this ideal situation to occur, the p-values in Table 6 without the superscript *a* (SR 56, SR 422 [Indiana County], SR 4422, and SR 422 [Armstrong County]) should be:

- At sensor #1: before-during and during-after comparisons – p-value > 0.05.
- At sensor #2: before-during comparison – p-value ≤ 0.05.
- At sensor #2: during-after comparison – p-value > 0.05.
- At sensor #3: before-during comparison – p-value ≤ 0.05.
- At sensor #3: during-after comparison – p-value > 0.05.

The SR 56 study site did exhibit the ideal or anticipated results; however, none of the remaining three sites where the speed limit remained constant exhibited the anticipated results. The primary reason that this scenario was not observed at these three locations was because the mean operating speed at the upstream data collection point (sensor #1) differed significantly when comparing either the before to during, or during to after, data collection time periods. Several interesting findings are of note:

- There was not a statistically significant difference in the mean operating speeds at the data collection point upstream of the speed minder location (sensor #1) during any of the data collection time periods at SR 56. This result was expected because this data collection point served as a control location where vehicle speeds were not expected to be different during any of the data collection time periods. At this location, the effect of the speed minder could be determined by simply subtracting the mean operating speed in the before period from the during period. The speed reduction attributed to the speed minder at this location was 9.0 mph.
- There was a statistically significant difference in the mean operating speeds at the data collection point upstream of the speed minder location (sensor #1) either between the before and during periods, or between the during and after periods, at 3 of 4 sites (SR 56, SR 422 [Indiana County], SR 4422, and SR 422 [Armstrong County]) where the posted speed limit did not change along the study segment. To determine the true effect of the speed minder at these locations, the analysis presented in the next section of the report must be used.
- At 3 of the 4 locations where the posted speed limit remained constant, the mean operating speed increased after the speed minders were removed from the site. The mean speeds were very similar after the speed minders were removed when compared to the time period before the speed minders were deployed.
- There was one study site location with a constant posted speed limit (SR 4422) where the speed minders were deployed for two consecutive weeks. At this location, the mean operating speeds at the speed minder location (sensor #2) were lower in the during period than before the speed minder was deployed. During

the second week of deployment, the speed reductions remained, suggesting that the speed minder was effective over a period longer than one week.

5.2 Test of Proportions for Vehicles Exceeding the Posted Speed Limit

Similar to the statistical tests of mean speed differences, tests to determine the difference between two proportions were performed to compare the percentage of vehicles exceeding the posted speed limit at each sensor location in successive time periods. It was assumed that the test results would be similar to the results for the point mean speed analysis presented in section 5.1. At the upstream sensor, it was hypothesized that the percentage of vehicles exceeding the posted speed limit would be equal in the before, during, and after time periods. At the speed minder location, it was expected that the percentage of vehicles exceeding the posted speed limit would be lower in the during period when compared to the before period. In the after period, based on the point speed analysis in section 5.1, it was expected that the percentage of vehicles exceeding the posted speed limit would be higher than in the during period. A similar trend was expected at the sensor #3 location. All of the statistical comparisons are shown in Appendix B.

The trends described above were observed at 7 of 17 sites (SR 192, segments 0270-0290; SR 322; SR 356; SR 422 in Armstrong County; SR 422 in Indiana County; SR 553; SR 3035). When comparing them to the point speed analysis results in section 5.1, the trends were nearly identical. In the point speed analysis, the anticipated results were observed at 7 of 17 sites (SR 53; SR 192, segments 0270-0290; SR 322; SR 356; SR 422 in Armstrong County; SR 553; SR 3035). The only difference was that the SR 53 site did follow the expected speed trend in the point speed analysis, but did not in the posted speed reduction analysis. In the posted speed reduction analysis, the SR 422 site in Indiana County exhibited the anticipated trend while it did not in the point speed analysis. Overall, the speed minders were associated with lower proportions of vehicles exceeding the posted speed limit when implemented; however, this effect generally did not endure after the speed minders were removed from the site.

5.3 Speed Differential Analysis

Comparing the mean speed at each sensor location before, during, and after speed minder implementation may either under- or overestimate the speed reduction attributable to the speed minder. An example of this is as follows, using the data from the Route 322 site in Jefferson County (see section A.17 in Appendix A):

- At the first sensor location upstream of the speed minder implementation point, the mean speed was 51.17 mph before the speed minder was implemented and was 51.94 mph during speed minder implementation. At the speed minder sensor (#2), the mean speed was 43.13 mph before speed minder implementation and 36.36 mph during speed minder activation. Using the analysis methods described earlier, there was not enough evidence in the observed data to conclude that the mean speeds were different at the upstream sensor (#1) when comparing the before and during periods. The difference in passenger car mean speeds at the speed minder location was 6.77 mph, a statistically significant difference in observed mean speeds. Using the analysis results presented earlier, one would conclude that the speed minder effect was a reduction in mean operating speeds of 6.77 mph.

- The speed distributions at each speed minder location differ for each data collection time period. Therefore, using the analysis methods presented earlier may produce different results than performing a similar analysis using speed differentials for each driver between successive point speed locations and then computing the mean speed reduction as follows:

$$T.E. = \Delta V_{1-2,DURING} - \Delta V_{1-2.,BEFORE} \tag{7}$$

where:

T.E. = the true effect of installing a speed minder;
$\Delta V_{1\text{-}2,\ DURING}$ = the mean speed reduction between sensors 1 and 2 in the “during” period; and
$\Delta V_{1\text{-}2,\ BEFORE}$ = the mean speed reduction between sensors 1 and 2 in the “before” period.

- Because Route 322 is a transition zone, a speed reduction between sensors #1 and #2 was expected. In the “before” period, the mean speed reduction was 8.04 mph (51.17 – 43.13). In the “during” period, the mean speed reduction was 15.58 mph (51.94 – 36.36). The difference between these (7.54 mph) is the true representation of the speed minder effectiveness. As noted earlier, the methods used in section 5.1 showed that the speed reduction at the speed minder point (sensor #2) was 6.77 mph, which was an underestimation of the “true effect” using tracked vehicles and speed differential data.

Table 7 shows the mean operating speeds at the Route 322 site for sensors #1 and #2 in both the before and during collection periods. Additionally, the true effect of speed minder implementation (7.54 mph) at this site is shown in Table 7. Table 7 also shows how the effect of the speed minder can be underestimated (6.77 mph) by considering only the speed difference at the sensor #2 location or overestimated (15.58 mph) by only considering the difference in speeds between sensors #1 and #2 during speed minder implementation. Figure 7 is a graphical illustration that shows how the speed differentials were computed between successive sensors during two different data collection time periods at the Route 322 site in Jefferson County.

Table 7. Mean Speeds for Route 322 at Sensors 1 and 2 for Before and During Periods.

Sensor	Period		Difference Before – During
	Before	During	
1	51.17	51.94	-
2	43.13	36.36	6.77
Difference Sensor 1 – Sensor 2	8.04	15.58	**T.E. = 7.54**

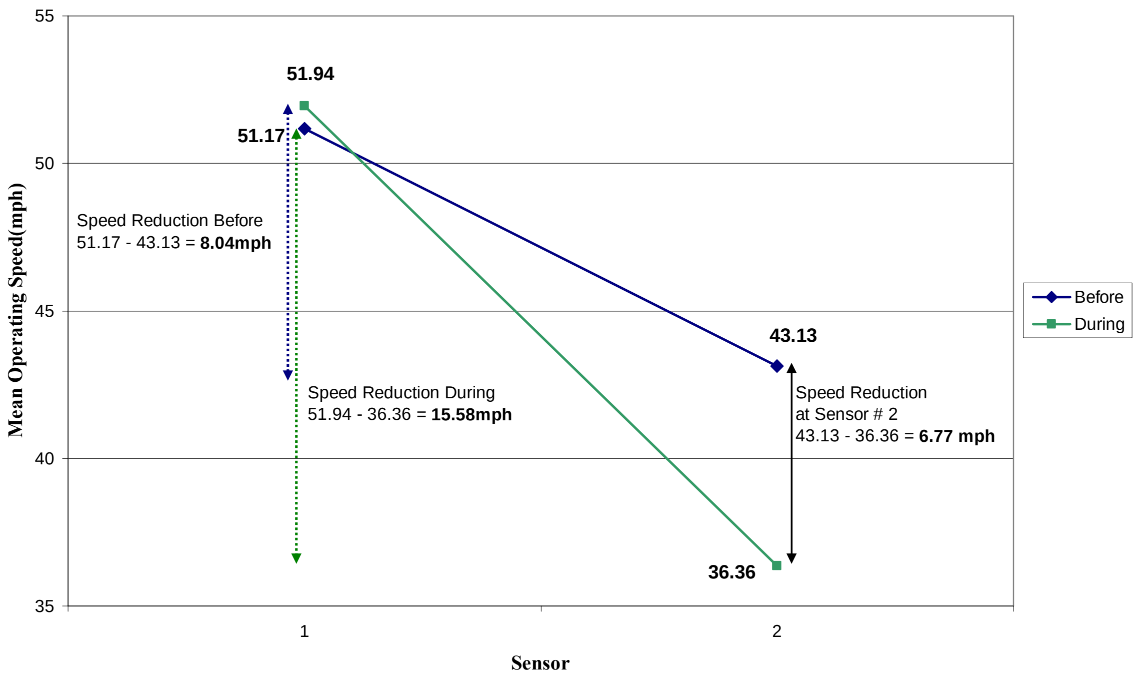

Figure 7. Speed Differential Example to Determine True Effect of Speed Minder.

For each "tracked" vehicle at each data collection site, the difference in speeds between sensor #1 (upstream of speed minder) and sensor #2 (adjacent to speed minder) was calculated for both the before and during data collection periods. A summary of the results is shown in Table 8. A positive value indicates that the speed minder was effective in reducing mean vehicle operating speeds by the value shown. Two-sample t-tests were performed to determine if the speed reductions were statistically significant. As shown in Table 8, all of the speed reductions were statistically significant except at Site ID 7, which corresponds to the Route 879 site in Clearfield County. The range of speed reductions was 2.2 mph to 11.9 mph.

Table 8. Speed Differentials between Sensors #1 and #2 for Before and During Data Collection Periods.

Site ID	Speed Reduction Before (mph)			Speed Reduction During (mph)			Speed Differential (During-Before) mph
	N	Mean	Std Dev	N	Mean	Std Dev	
1	122	9.12	6.60	155	19.67	7.05	10.55*
2	95	6.58	7.53	99	14.24	8.67	7.66*
3	53	12.25	8.18	66	24.18	8.66	11.93*
4	81	10.27	7.15	119	15.93	6.44	5.66*
5	52	13.75	7.78	63	18.03	6.98	4.28*
6	99	13.45	9.95	94	18.64	9.04	5.19*
7	121	21.97	6.18	119	22.72	8.24	0.75
8	96	-1.44	9.02	99	4.40	8.02	5.84*
9	134	4.50	7.93	180	6.67	7.42	2.17*
10	129	0.74	7.50	186	9.18	7.36	8.44*
11	112	-4.16	7.89	161	-0.53	8.44	3.63*
12	111	3.14	9.13	107	5.86	9.26	2.72*
13	152	9.88	6.69	143	14.81	6.91	4.93*
14	150	-2.52	7.33	109	1.27	7.57	3.79*
15	148	2.19	6.47	243	8.83	7.30	6.64*
16	173	9.80	5.75	172	11.96	7.01	2.16*
17	99	8.04	7.83	143	15.57	7.28	7.53*

* indicates that two-sample t-test was statistically significant at $\alpha = 0.05$ level.
Std Dev = standard deviation of observed speeds.

Additional analyses were performed in order to study the relationship of the speed reduction between sensors #1 and #2 for both the before and during periods. It was hypothesized that the speed reduction resulting from speed minder implementation can be predicted by knowing the speed reduction before implementing the device. Therefore, the effectiveness of a speed minder at a particular site can be predicted if the speed reductions before implementation are known. One method to determine the mean speed reductions at a site where a speed minder may be implemented is to collect approximately 100 free-flow passenger car vehicle speeds at a location ½-mile upstream of the speed minder site and at the proposed speed minder location. The difference in the mean speeds at these two point locations is the speed differential that can be used in the prediction equation presented below. If speed data cannot be collected prior to speed minder implementation, it is recommended that the following speed reductions be used (based on the present experiment):

- If the proposed speed minder site does not contain a change in the regulatory speed, the speed differential in the “before” period should be 0 mph.

- If the proposed speed minder site does contain a change in the regulatory speed (i.e., posted speed limit), the speed differential in the "before" period should be one-half the change in the posted speed limit. This was computed as follows:
  - Consider sites #1, #3, #15, and #16 in Table 8. The change in the posted speed limit at these four sites is 15 mph. As shown in the "Speed Reduction Before" column in Table 8, the mean speed reduction at these sites was 9.1, 12.2, 2.2, and 9.8 mph, respectively. The mean of the mean speed reduction is 8.3 mph, or approximately one-half of the regulatory speed reduction.
  - Consider sites #2, #4 through #7, #10, #12, #13, and #17 in Table 8. The change in the posted speed limit at these sites is 20 mph. The average of the before period mean speed reduction was 9.8 mph, or approximately one-half the regulatory speed reduction.

For each site, the mean speed reduction for the before and during periods were plotted on separate axes as shown in Figure 8. The plot shown in Figure 8 indicates a positive linear relationship between the two speed reduction variables.

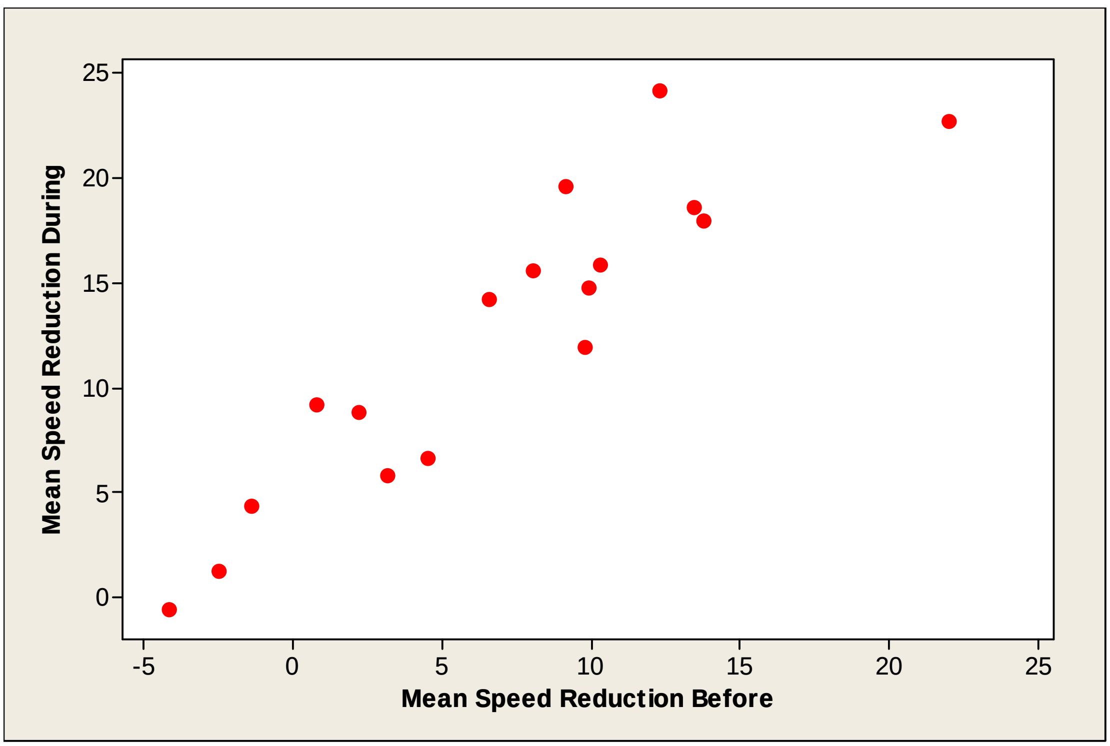

Figure 8. Plot of Mean Speed Reductions in Before and During Periods.

A linear regression model was specified to determine if the mean speed reduction in the during period is correlated with the mean speed reduction in the before period. The regression equation developed was as follows:

$$\Delta V_{1-2,DURING} = 5.68 + 0.98 \Delta V_{1-2.,BEFORE} \quad (8)$$

The regression equation has an R^2 value of 0.817, indicating that the independent variable (speed reduction in the before period) explains about 82 percent of the variability of the speed reduction in the during period. The value of the constant indicates that, on average, speed minders are able to reduce speeds by almost 6 mph. The value of the before period speed reduction coefficient indicates that for every mile per hour of speed reduction in the before period, a one mile per hour speed reduction in the during period is expected. As such, the greater the regulatory speed change at a proposed speed minder site, the higher the expected speed reduction that can be attributed to the speed minder device.

As shown in section 5.1 above, it is clear that the effectiveness of the speed minder dissipates almost immediately after removing it from a site. As noted above, the analysis presented in section 5.1 may either over- or underestimate the speed differential if independently considering the mean operating speeds at each sensor location for each data collection period. For example, consider the Route 322 analysis presented earlier.

- At the first sensor location upstream of the speed minder implementation point, the mean speed was 51.94 mph during the time period when the speed minder was implemented and was 51.68 mph after the speed minder was removed from the site. At the speed minder sensor (#2), the mean speed was 36.36 mph during speed minder implementation and 44.42 mph after the speed minder was removed from the site. Using the analysis methods described in section 5.1, the difference in passenger car mean speeds between the during and after periods was 8.06 mph.
- Using equation 9 below, the speed differential is 8.32 mph; therefore, the analyses presented in section 5.1 would underestimate the speed increase after the speed minder was removed from the site.

$$N.E. = \Delta V_{1-2,AFTER} - \Delta V_{1-2.,DURING} \quad (9)$$

where:

$N.E.$ = the negative mean speed effect of removing a speed minder;
$\Delta V_{1\text{-}2,\ AFTER}$ = the mean speed reduction between sensors #1 and #2 in the after period; and
$\Delta V_{1\text{-}2,\ DURING}$ = the mean speed reduction between sensors #1 and #2 in the during period.

Similar as the true effect of the speed minder, the equation for calculating the negative effect of the speed minder ensures that any speed reductions associated with other factors are not considered, thus isolating the negative effects of removing the device. Table 9 shows a summary of the results obtained using equation 9.

Table 9. Speed Differentials between Sensors #1 and #2 for During and After Data Collection Periods.

Site ID	Speed Reduction During (mph)			Speed Reduction After (mph)			Speed Differential (After-During) mph
	N	Mean	Std Dev	N	Mean	Std Dev	
1	155	19.67	7.05	105	11.10	5.49	-8.57*
2	99	14.24	8.67	105	6.19	7.62	-8.05*
3	66	24.18	8.66	96	15.83	10.53	-8.35*
4	119	15.93	6.44	205	7.30	6.23	-8.63*
5	63	18.03	6.98	91	15.36	8.36	-2.67*
6	94	18.64	9.04	135	16.19	8.62	-2.45*
7	119	22.72	8.24	139	16.49	6.22	-6.23*
8	99	4.40	8.02	89	0.75	7.42	-3.65*
9	180	6.67	7.42	126	5.63	7.65	-1.04
10	186	9.18	7.36	141	1.30	6.98	-7.88*
11	161	-0.53	8.44	173	-1.93	11.05	-1.40
12	107	5.86	9.26	104	0.57	7.99	-5.29*
13	143	14.81	6.91	156	8.39	7.95	-6.42*
14	109	1.27	7.57	142	-3.69	8.67	-4.96*
15	243	8.83	7.30	182	2.88	7.32	-5.95*
16	172	11.96	7.01	172	6.07	5.29	-5.89*
17	143	15.57	7.28	186	7.26	8.19	-8.31*

* indicates that two-sample t-test was statistically significant at $\alpha = 0.05$ level.
Std Dev = standard deviation of observed speeds.

All of the speed differentials in Table 9 are negative, indicating that the speed reductions observed in the after period were lower than those in the during period. Alternatively stated, removing the speed minder resulted in a mean speed increase at all 17 data collection sites within a period of 1 week after the device was removed. The two-sample t-test indicated that this speed increase was statistically significant at 15 of 17 sites. The range of this speed increase was 2.5 to 8.6 mph.

Similar to predicting the true effect of a speed minder, the negative effect of removing a speed minder can be predicted using data from the during and after periods. Figure 9 shows a scatterplot of the observed mean speed reductions in the during and after periods. It is clear that a linear relationship exists between these variables.

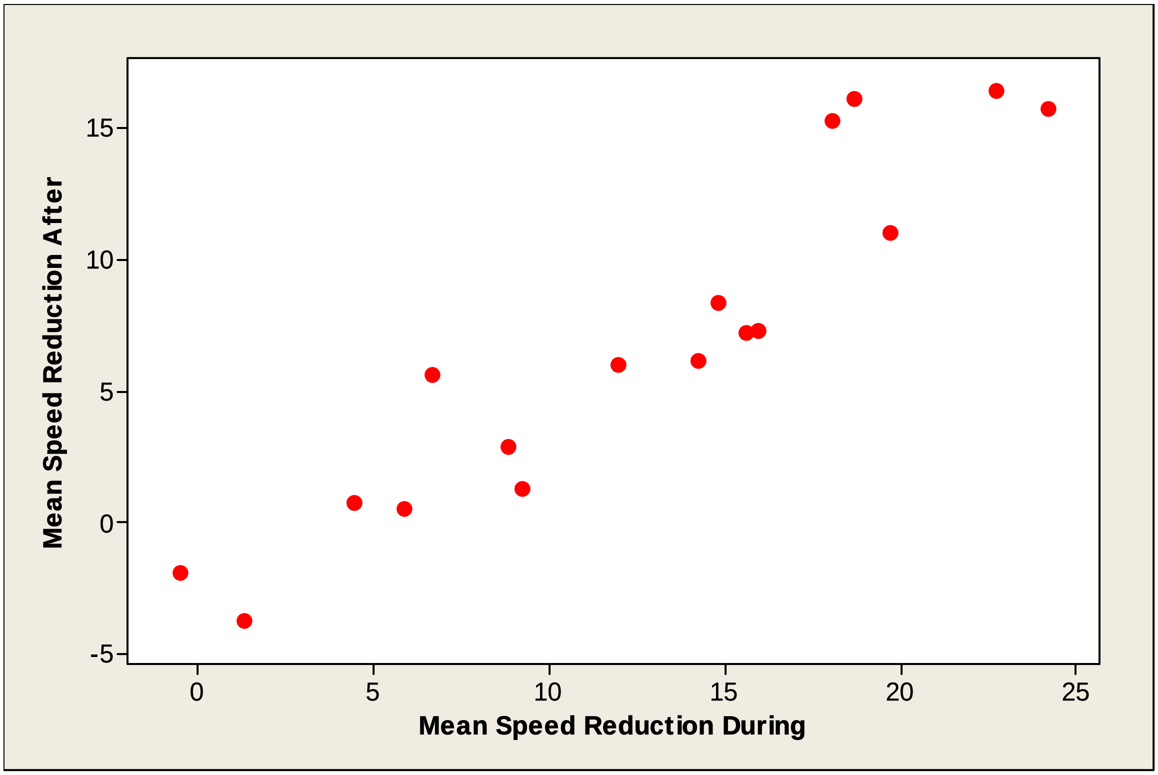

Figure 9. Plot of Mean Speed Reductions in During and After Periods.

A linear regression model was developed to predict the mean speed reduction in the after period using the speed reduction from the during period. The regression equation is shown below:

$$\Delta V_{1-2,AFTER} = -3.50 + 0.83\Delta V_{1-2.,DURING} \qquad (10)$$

The results of the regression analysis indicate that the explanatory variable (change in speed between sensors #1 and #2 in the during period) explains 87 percent of the variability in the change in speed in the after period between sensors #1 and #2. For each one mile per hour of speed reduction in the during period, there is an expected 0.83 mile per hour of speed reduction in the after period. In addition, removing a speed minder has a general effect of increasing speeds by 3.5 mph. To use equation 10, it is recommended that the $\Delta V_{1-2,\ DURING}$ variable be calculated using equation 8 and then input into equation 10. If the speed reduction computed using equation 8 is positive, it should be entered into equation 10 as a positive number, and vice versa.

6.0 CONCLUSIONS

Each PennDOT engineering district has invested in several speed minders in an effort to reduce vehicle operating speeds along roadways within the district, particularly those that transition from a high- to low-speed operating environment. PennDOT's current program to deploy the devices is to implement them for a period of 1 week at a site and then move them to other locations so that wide geographic coverage is obtained within each district. The purpose of this study was to evaluate the effectiveness of the speed minder devices by determining the magnitude of speed reduction that can be attributed to the devices. Speed data were collected at 17 sites in Engineering Districts 2-0 and 10-0. The sites were a combination of transition zones (i.e., regulatory speeds are reduced at site) and sites that did not contain a change in the regulatory speed. Data were collected before, during, and after placement of the devices at each site. Consistent with PennDOT's deployment program, the devices were placed and activated at 13 of 17 sites for a period of 1 week. At the four remaining sites, the devices were placed and activated for a period of 2 consecutive weeks. The purpose of this longer evaluation period was to determine if the speed minder retained its effectiveness over a longer period of time.

The results indicate that the speed minders were effective in reducing mean passenger car speeds at all sites when the devices were deployed for a period of 1 week. The speed reductions were, on average, greater at locations where the regulatory speed changed than at locations where the regulatory speed did not change. The average speed reduction observed along the transition zones was approximately 6 mph. At the locations where the regulatory speed did not change, the average speed reduction was approximately 4 mph. At the locations where the speed minders were deployed for a period of 1 week, the observed mean speeds generally increased in the week after the speed minders were removed from the site. The average increase in speeds 1 week after the speed minder was removed from the site was 6.5 mph for the transition zones and approximately 3 mph in the segments where the posted speed limit did not change. This suggests that deploying the speed minders for a period of 1 week has the desired effect of reducing mean speeds while in place, but after their removal the speeds return to approximately the same level as prior to deployment.

To address the issue of long-term effects associated with the speed minder, the device was deployed for 2 weeks at four study sites. At these sites, the average speed reduction observed in the first week after deployment of the speed minder was approximately 5 mph. At all four sites, the speeds remained constant during the second week of deployment, suggesting that the speed minders retained their effectiveness. Within the 2-week period after removing the speed minders, the observed mean speeds, on average, returned to the same level as before the speed minders were deployed. These findings suggest that there may be a benefit associated with deploying the speed minders for a long duration at sites in Pennsylvania, rather than deploying them for a single week.

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APPENDIX A
Individual Point Speed Site Analysis Results

This section of the report presents the analysis results based on the methodology described in section 4.0. It contains results from each individual study site where speeds were compared before, during, and after speed minder implementation at each sensor location. Please refer to Figure 4 on page 15 for a graphical illustration of the placement of sensors #1, #2, and #3 in relation to the speed minder device at each study site.

Presentation of the results is organized by providing the descriptive statistics from each site for the before, during, and after data collection periods. Then, the statistical tests used to compare the mean speed differences at each point speed location are presented for each data collection period. Finally, a graphical illustration of the mean speeds is presented for each data collection time period, followed by an interpretation of the analysis results.

A.1 Route 550 Northbound, Centre County

As noted in Table 4, the Route 550 site is located in Centre County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder implementation point. The posted speed is 40 mph at the speed minder point and at the data collection location 500 ft downstream of the speed minder point. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-1. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-2. Figure A-1 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-1. Descriptive Statistics of Speeds along State Route 550 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	122	53.11	58.85	5.6834	36.9
	During	155	56.01	61.90	5.8565	51.6
	After	105	53.56	58.00	5.0553	34.3
2 At Speed Minder	Before	122	43.99	50.00	6.0583	71.3
	During	155	36.34	41.00	5.0702	23.2
	After	105	42.46	48.00	4.9381	65.7
3 500-ft Downstream Speed Minder	Before	122	39.81	45.00	5.4838	41.0
	During	155	36.15	41.90	5.5675	23.2
	After	105	39.09	45.00	6.3156	36.2

Table A-2. Statistical Tests of Mean Speed Differences for State Route 550.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	53.11	56.01	-4.16	0.000
	During - After	56.01	53.56	3.59	0.000
2	Before – During	43.99	36.34	11.20	0.000
	During - After	36.34	42.46	-9.70	0.000
3	Before – During	39.81	36.15	5.48	0.000
	During - After	36.15	39.09	-3.86	0.000

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

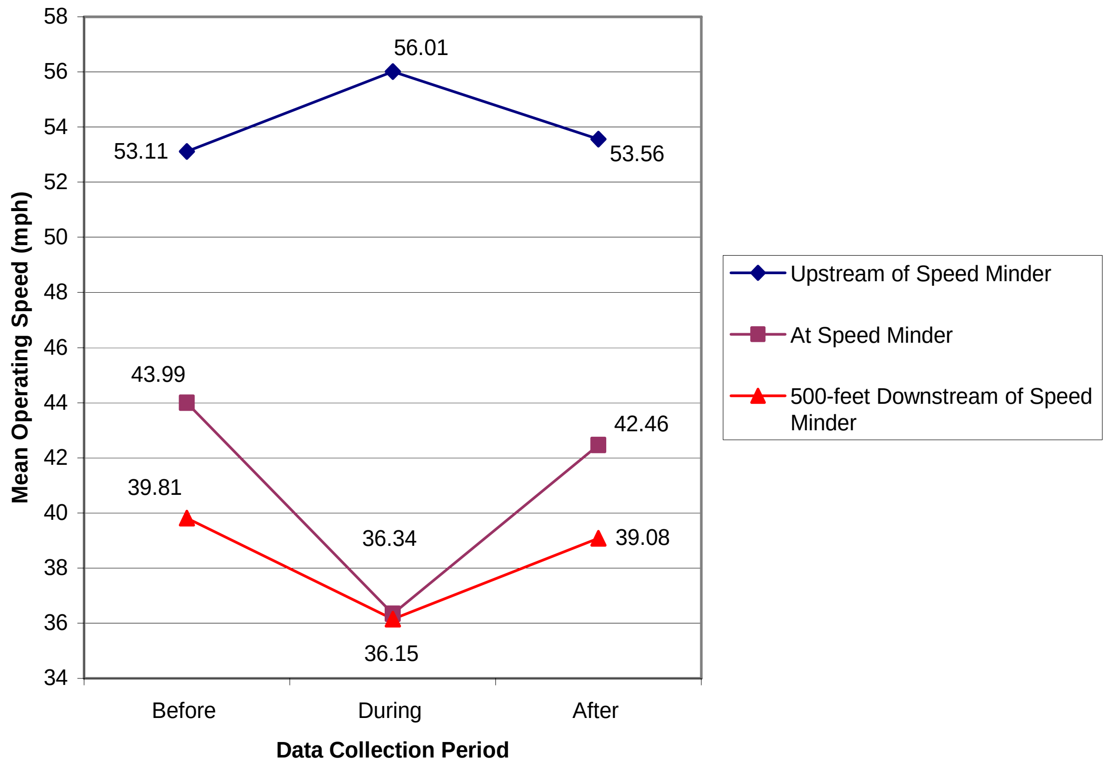

Figure A-1. Speed Profile Plot for State Route 550.

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. If this result was proven by the statistical analysis, then it is reasonable to conclude that the effect of the speed minder could be captured by simply computing the difference in mean speeds at the speed minder implementation point (sensor #2). If this was not the case, an alternative analysis would be required, as discussed in section 5.3.

It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 40 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2. If the observed mean speeds were higher after the speed minder location, then motorists likely perceived the speed minder as a form of enforcement and, after passing by the device, accelerated to a speed they considered appropriate for the operating environment. If motorists continued to decelerate, it was hypothesized that the speed minder had the desirable effect of reducing speeds in the transition zone to a level near the regulatory speed.

The t-tests shown in Table A-2 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that the mean speeds at sensor #1 were higher in the during period than in the before period, and that the mean speeds were lower in the after period than in the during period. The results were statistically significant. This result was not expected, as the speed minder device was not visible to motorists at the upstream data collection point. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 7.7 mph. After the speed minder was removed, the mean speeds increased at sensor #2 by 6.1 mph, almost returning to the same level as before the speed minder was implemented. At the downstream sensor location (#3), the mean speeds decreased by 3.7 mph after the speed minder was implemented, but increased by nearly 3.0 mph after the speed minder was removed from the study site. All statistical tests were significant. These findings suggest that the speed minders were effective in reducing the mean speeds at and downstream of the speed minder location while the device was in place and activated; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level that was nearly equal to the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-1. As shown in Figure A-1, the mean speeds were lower at the downstream sensor location (#3) when compared to the speed minder location (sensor #2) in the before and after periods. This suggests that the regulatory speed change is influencing vehicle operating speeds. While the speed minder was implemented, the during period speeds at the speed minder point (sensor #2) and downstream of the speed minder (sensor #3) were nearly equal, which suggests that the speed minder likely contributed to speed reductions occurring over a shorter longitudinal distance when the device was activated.

A.2 Route 192 Eastbound, Centre County (Segments 0270-0290)

As noted in Table 4, the Route 192 site, segments 0270 to 0290, is located in Centre County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-3 The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-4. Figure A-2 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-3. Descriptive Statistics of Speeds at State Route 192 (Segments 0270-0290) Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85th-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	95	55.43	60.00	6.0277	43.2
	During	99	55.42	62.00	6.5436	47.5
	After	105	56.57	63.00	7.1075	59.0
2 At Speed Minder	Before	95	48.85	55.00	6.4610	96.8
	During	99	41.18	48.00	6.5549	81.8
	After	105	50.38	57.00	7.3004	97.1
3 500-ft Downstream Speed Minder	Before	95	50.33	57.00	6.7783	97.9
	During	99	40.65	46.00	5.1036	79.8
	After	105	48.96	55.40	7.0328	98.1

Table A-4. Statistical Tests of Mean Speed Differences for State Route 192 (Segments 0270-0290).

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	55.43	55.42	0.01	0.991
	During - After	55.42	56.57	-1.20	0.230
2	Before – During	48.85	41.18	8.21	0.000
	During - After	41.18	50.38	-9.48	0.000
3	Before – During	50.33	40.65	11.20	0.000
	During - After	40.65	48.96	-9.70	0.000

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2 \neq 0$)
* mean speed difference is statistically significant at $\alpha = 0.05$

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

The t-tests shown in Table A-4 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that, as expected, the difference in mean speeds at sensor #1 was not statistically significant in any of the data collection time periods. This indicates that the speed reductions associated with the speed minder can be based on the speed reductions obtained at sensor #2, the speed minder implementation point. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 7.7 mph. After the speed minder was removed, the mean speeds increased at sensor #2 by 9.2 mph, speeds that were higher than before the speed minder was implemented. At the downstream sensor location (#3), the mean speeds decreased by 9.7 mph after the speed minder was implemented. The mean speeds increased by nearly 8.3 mph at the downstream sensor after the speed minder was removed. All statistical tests at sensors #2 and #3 were significant. These findings suggest that the speed minder was effective in reducing the mean speeds at and downstream of the speed minder location while the device was in place and activated; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level that was nearly equal to the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-2. As shown in Figure A-2, the speed plots are nearly parallel at the speed minder location and at the location 500 ft downstream of the speed minder. This suggests that the speed minder did not significantly influence the longitudinal distance over which the speed reductions occurred in the transition zone.

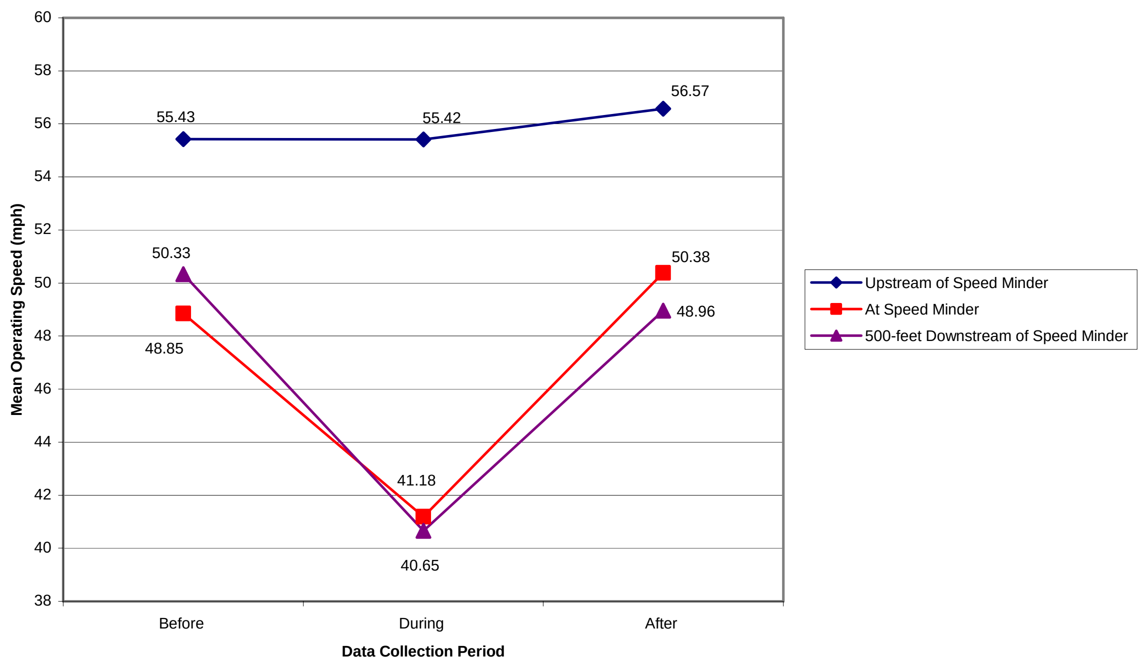

Figure A-2. Speed Profile Plot for State Route 192 (Segments 0270-0290).

A.3 Route 192 Eastbound, Centre County (Segments 0210-0220)

As noted in Table 4, the Route 192 site, segments 0210 to 0220, is located in Centre County and was located approximately three miles upstream of the site described in section 5.1.2 above. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 40 mph at the speed minder implementation point and at the data collection location 500 ft downstream of the speed minder implementation point.

Because this site was located approximately three miles upstream of the site described in section 5.1.2, the authors sought to minimize any bias from having two speed minders placed on the same roadway, by collected data at the downstream segment first (segments 0270-0290). It was assumed that with placement of the speed minder at the upstream site afterwards, vehicle drivers would not be expecting the speed minder device, thus eliminating the possibility of collecting biased data.

The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-5. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-6. Figure A-3 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-5. Descriptive Statistics of Speeds at State Route 192 (Segments 0210-0220) Location.

Sensor	**Time Period**	**Sample Size**	**Mean Speed (mph)**	**85th-percentile Speed (mph)**	**Standard Deviation of Speed (mph)**	**Percent Exceeding Posted Speed Limit**
1 Upstream of Speed Minder	Before	53	55.11	59.20	6.3296	43.4
	During	66	60.83	67.25	7.2612	72.7
	After	96	60.60	67.75	6.9061	82.3
2 At Speed Minder	Before	53	42.87	50.20	8.1619	69.8
	During	66	36.65	43.00	6.6668	28.8
	After	96	44.77	53.00	8.8799	69.8
3 500-ft Downstream Speed Minder	Before	53	45.85	54.00	7.4302	77.4
	During	66	42.42	47.25	5.1143	68.2
	After	96	46.21	53.00	7.4097	80.2

Table A-6. Statistical Tests of Mean Speed Differences for State Route 192 (Segments 0210-0220).

Sensor	**Comparison Test**	**Before Mean Speed**	**After Mean Speed**	**t-statistic**	**p-value**
1	Before – During	55.11	60.83	-4.59	0.000
	During - After	60.83	60.60	0.20	0.840
2	Before – During	42.87	36.65	4.48	0.000
	During - After	36.65	44.77	-6.64	0.000
3	Before – During	45.85	42.42	2.86	0.005
	During - After	42.42	46.21	-3.85	0.000

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder implementation point along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 40 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

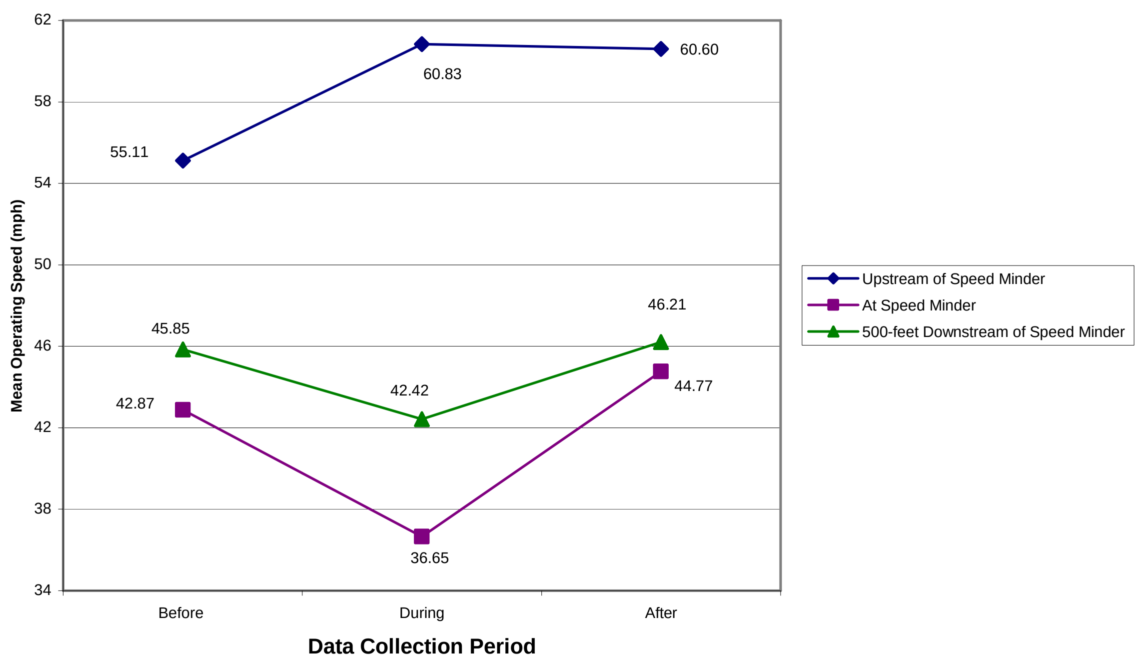

Figure A-3. Speed Profile Plot for State Route 192 (Segments 0210-0220).

The t-tests shown in Table A-6 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that the difference in mean speeds at sensor #1 was statistically significant when comparing the before to during periods (higher speeds in during period); however, no statistically significant difference was observed when comparing the during and after periods at the upstream sensor location. This result was not expected and, therefore, the speed differential analysis described in section 5.3 will provide a more accurate representation of the speed minder effect at this particular site.

At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 6.2 mph. After the speed minder was removed, the mean speeds increased at sensor #2 by 8.1 mph. At the downstream sensor location (#3), the mean speeds decreased by 3.4 mph after the speed minder was implemented. The mean speeds increased by nearly 3.8 mph at the downstream sensor after the speed minder was removed. All statistical tests at sensors #2 and #3 were significant. These findings suggest that the speed minders were effective in reducing the mean speeds at and downstream of the speed minder location while the device was in place and activated; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level higher than the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-3. As shown in Figure A-3, the mean speeds were higher at the downstream sensor location (#3) when compared to the speed minder location (sensor #2) for all data collection periods, particularly in the during period. This suggests that the speed minder did not significantly influence vehicle operating speeds downstream of the device while activated, as drivers tended to accelerate immediately after passing the device.

A.4 Route 53 Northbound, Clearfield County

As noted in Table 4, the Route 53 site is located in Clearfield County. This route is a transition zone where the posted speed limit is 45 mph at the data collection location upstream of the speed minder site. The posted speed is 25 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site.

The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-7. Data were collected over five periods: before speed minder implementation, two during implementation periods, and two periods after removal of the speed minder device. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-8. Figure A-4 shows the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-7. Descriptive Statistics of Speeds at State Route 53 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85th-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	81	46.95	53.00	6.5228	55.6
	During 1	119	45.20	51.00	5.5074	43.7
	During 2	194	44.03	49.00	5.4937	37.6
	After 1	205	44.03	50.00	5.6032	39.0
	After 2	193	44.77	51.00	5.8240	45.6
2 At Speed Minder	Before	81	36.68	43.00	6.0287	95.1
	During 1	119	29.27	35.00	5.5045	75.6
	During 2	194	29.72	35.00	5.0702	80.9
	After 1	205	36.73	42.40	5.6405	98.0
	After 2	193	36.36	42.00	5.6174	97.4
3 500-ft Downstream Speed Minder	Before	81	32.54	39.00	5.5970	91.4
	During 1	119	29.86	35.30	5.3095	81.5
	During 2	194	30.25	35.00	4.5877	85.1
	After 1	205	34.42	39.00	4.9824	95.6
	After 2	193	33.66	39.00	5.1140	95.9

Table A-8. Statistical Tests of Mean Speed Differences for State Route 53.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During 1	46.95	45.20	1.98	0.049
	During 1 – During 2	45.20	44.03	1.83	0.069
	During 2 – After 1	44.03	44.03	0.00	1.000
	After 1 – After 2	44.03	44.77	-1.29	0.198
2	Before – During 1	36.68	29.27	8.84	0.000
	During 1 – During 2	29.27	29.72	-0.72	0.470
	During 2 – After 1	29.72	36.73	-13.07	0.000
	After 1 – After 2	36.73	36.36	0.66	0.513
3	Before – During 1	32.54	29.86	3.39	0.001
	During 1 – During 2	29.86	30.25	-0.66	0.508
	During 2 – After 1	30.25	34.42	-8.70	0.000
	After 1 – After 2	34.42	33.66	1.50	0.134
Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

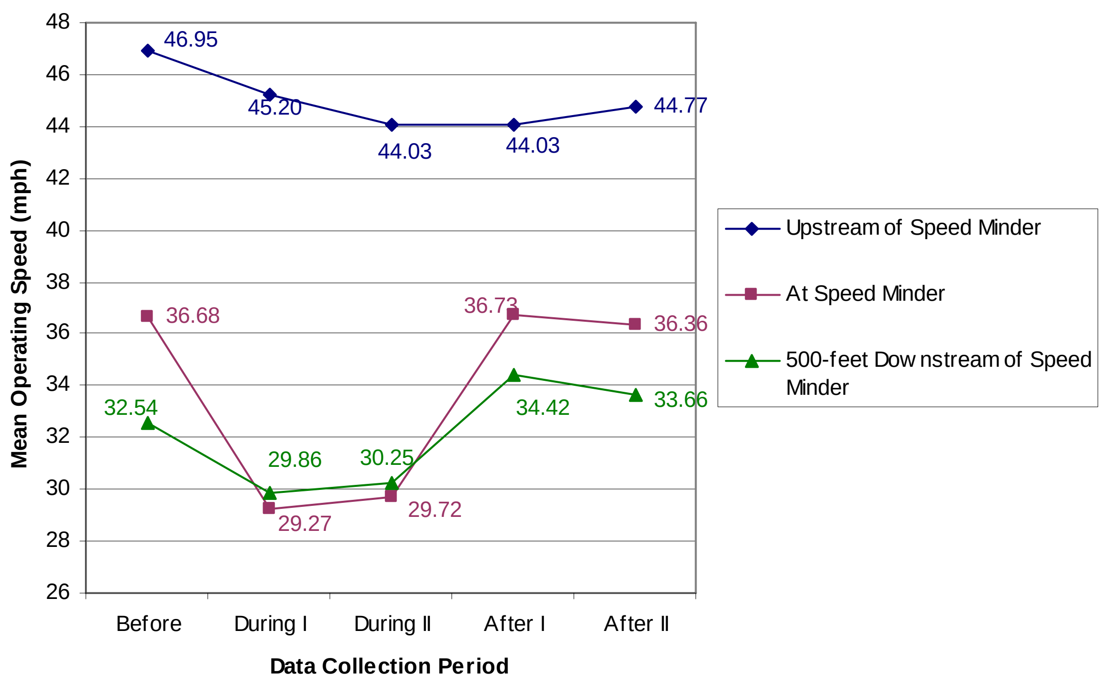

Figure A-4. Speed Profile Plot for State Route 53.

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder implementation point along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 45 to 25 mph.

During the 2 weeks that the speed minder was in place (during period #1 and #2), it was expected that the observed free-flow speeds would be lower than those observed in the before period. It was also expected that the mean speeds would remain nearly constant at sensor #2 in both during data collection periods. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2 during all data collection periods.

The t-tests shown in Table A-8 compare the mean speeds at each sensor location at all five data collection time periods. The results indicate that the difference in mean speeds at sensor #1 was statistically significant when comparing the before to the first during period; however, no statistically significant difference was observed when comparing subsequent data collection time periods at the upstream sensor location. At the speed minder location, the mean speeds were lower in the first during period than in the before period by approximately 7.4 mph. As expected, no statistically significant difference was found between the first and second during time periods, indicating that the speed minder remained effective during the second week of activation. After the speed minder was removed, the mean speeds increased at sensor #2 by 7.0 mph. No statistically significant difference in mean speed was observed when comparing the two after data collection periods at sensor #2. At the downstream sensor location (#3), the mean speeds decreased by 2.7 mph after the speed minder was implemented. As expected, no statistically significant change in mean speeds was observed during the second week of speed minder activation at the downstream sensor location. The mean speeds increased by approximately 4.1 mph at the downstream sensor after the speed minder was removed. No statistically significant change in mean speeds occurred when comparing the first and second after time periods. These findings suggest that the speed minders were effective in reducing the mean speeds at and downstream of the speed minder location while the device was in place and activated for both during time periods; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level that was nearly equal to or higher than the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-4.

A.5 Route 3040 Northbound, Centre County

As noted in Table 4, the Route 3040 site is located in Centre County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site.

The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-9. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-10. It should be noted that there were two during and two after data collection periods along Route 3040 to determine if the speed minders remained effective throughout the 2-week period of implementation. Figure A-5 shows the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A- 9. Descriptive Statistics of Speeds at State Route 3040 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	52	57.71	65.35	7.6909	67.3
	During 1	63	53.67	59.00	5.6426	36.5
	During 2	126	55.06	61.00	6.4241	45.2
	After 1	91	56.30	63.00	6.2725	58.2
	After 2	84	54.35	60.00	5.6344	41.7
2 At Speed Minder	Before	52	43.96	51.35	7.5588	84.6
	During 1	63	35.63	40.70	5.7902	50.8
	During 2	126	35.48	40.00	4.6540	42.9
	After 1	91	40.93	46.50	6.7640	86.8
	After 2	84	42.90	49.00	6.5060	88.1
3 500-ft Downstream Speed Minder	Before	52	43.35	50.35	8.0095	86.5
	During 1	63	37.03	42.00	5.0544	61.9
	During 2	126	35.98	40.00	4.4000	52.4
	After 1	91	39.58	45.00	5.9143	79.1
	After 2	84	42.12	48.55	7.0016	88.1

Table A-10. Statistical Tests of Mean Speed Differences for State Route 3040.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During 1	57.71	53.67	3.15	0.002
	During 1 – During 2	53.67	55.06	-1.52	0.130
	During 2 – After 1	55.06	56.30	-1.42	0.156
	After 1 – After 2	56.30	54.35	2.17	0.032
2	Before – During 1	43.96	35.63	6.52	0.000
	During 1 – During 2	35.63	35.48	0.18	0.858
	During 2 – After 1	35.48	40.93	-6.64	0.000
	After 1 – After 2	40.93	42.90	-1.96	0.051
3	Before – During 1	43.35	37.03	4.94	0.000
	During 1 – During 2	37.03	35.98	1.40	0.163
	During 2 – After 1	35.98	39.58	-4.91	0.000
	After 1 – After 2	39.58	42.12	-2.58	0.011

Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the 2 weeks that the speed minder was in place (during period #1 and #2), it was expected that the observed free-flow speeds would be lower than the mean speeds observed in the before period. It was also expected that the mean speeds in the 2-week during period would be near constant. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2 during all data collection periods.

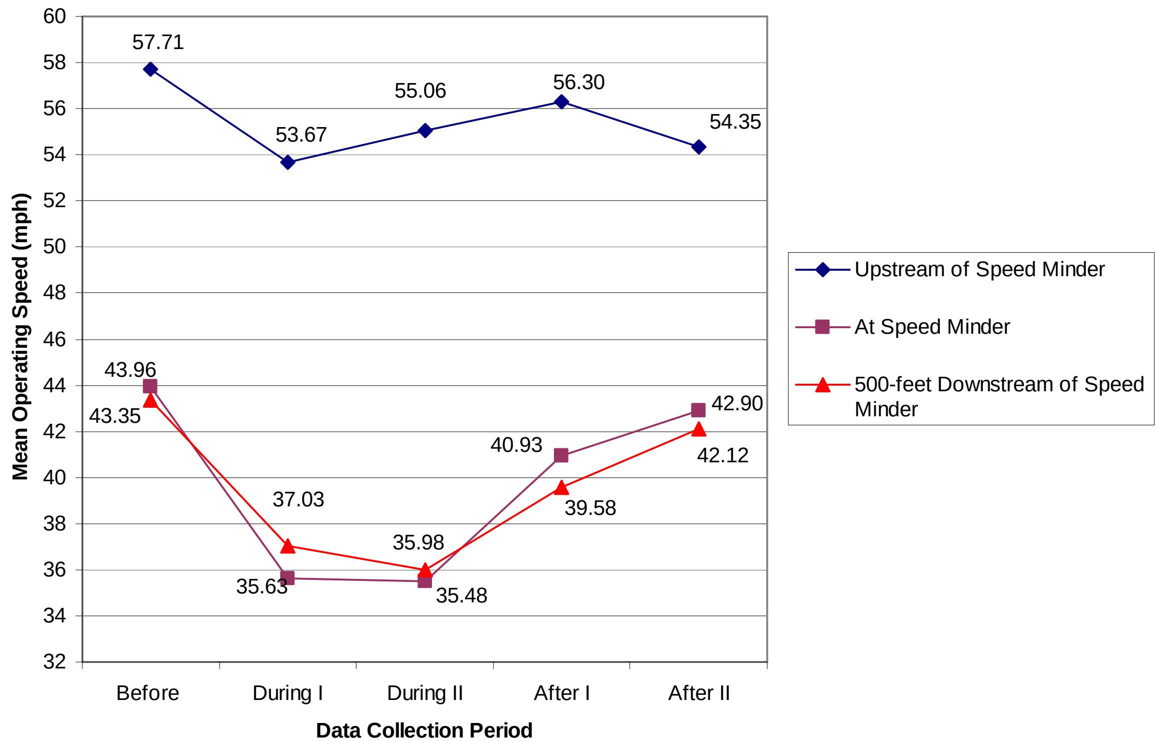

Figure A-5. Speed Profile Plot for State Route 3040.

The t-tests shown in Table A-10 compare the mean speeds at each sensor location during all five data collection time periods. The results indicate that, the difference in mean speeds at sensor #1 were statistically significant when comparing the before to the first during period; however, no statistically significant difference was observed when comparing the two during periods and the first after and second during periods. There was a statistically significant increase in the observed mean speeds between the two after periods. These results were not expected; therefore, the speed reduction analysis described in section 5.3 will provide a more accurate representation of the speed minder effect.

At the speed minder location, the mean speeds were lower in the first during period than in the before period by approximately 8.3 mph. As expected, no statistically significant difference was found between the first and second during time periods, indicating that the speed minder remained effective during the second week of activation. After the speed minder was removed, the mean speeds increased at sensor #2 by 5.5 mph during the first after period. No statistically significant difference in mean speed was observed when comparing the two after data collection periods. At the downstream sensor location (#3), the mean speeds decreased by 6.3 mph after the speed minder was implemented. No statistically significant change in mean speed was observed during the second week of speed minder activation at the downstream sensor location. The mean speeds increased by approximately 3.6 mph at the downstream sensor after the speed minder was removed. A statistically significant increase of 2.5 mph occurred when comparing the first and second after data collection time periods. These findings suggest that the speed minders were effective in reducing the mean speeds at and downstream of the speed minder location while the device was in place and activated for both during time periods; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level that was nearly equal to the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-5. As shown in Figure A-5, the speed plots are nearly parallel at the speed minder location and at the location 500 ft downstream of the speed minder. This suggests that the speed minder did not significantly influence the longitudinal distance over which speed changes occurred in the transition zone.

A.6 Route 453 Northbound, Clearfield County

As noted in Table 4, the Route 453 site is located in Clearfield County. This route is a transition zone where the posted speed limit is 45 mph at the data collection location upstream of the speed minder implementation point. The posted speed is 25 mph at the speed minder implementation point and at the data collection location 500 ft downstream of the speed minder point. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-11. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-12. Figure A-6 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-11. Descriptive Statistics of Speeds at State Route 453 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85th-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	99	42.52	49.30	7.9724	34.3
	During	94	44.98	53.00	7.9447	45.7
	After	135	45.61	51.90	6.6658	54.8
2 At Speed Minder	Before	99	29.06	37.00	6.2382	63.6
	During	94	26.34	32.00	4.9894	46.8
	After	135	29.42	35.00	5.7814	74.1
3 500-ft Downstream Speed Minder	Before	99	28.63	33.00	3.9112	81.8
	During	94	28.05	33.00	5.1834	70.2
	After	135	28.34	33.00	4.4204	69.6

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 45 to 25 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would be lower than those observed in the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

Table A-12. Statistical Tests of Mean Speed Differences for State Route 453.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	42.52	44.98	-2.15	0.033
	During - After	44.98	45.61	-0.66	0.510
2	Before – During	29.06	26.34	3.35	0.001
	During - After	26.34	29.42	-4.30	0.000
3	Before – During	28.63	28.05	0.87	0.383
	During - After	28.05	28.34	-0.44	0.659

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

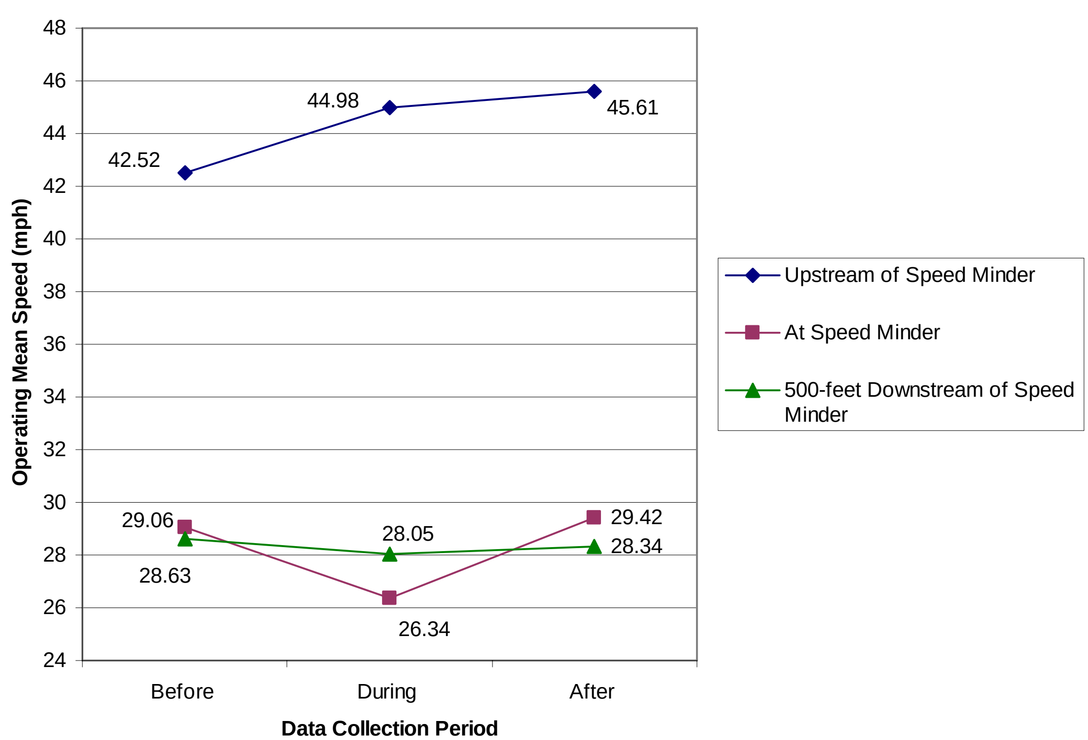

Figure A-6. Speed Profile Plot for State Route 453.

The t-tests shown in Table A-12 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that the difference in mean speeds at sensor #1 was statistically significant when comparing the before and during periods, but not different when comparing the during and after periods. This result was not expected and therefore the speed reduction analysis presented in section 5.3 will provide a more accurate representation of the speed minder effect at this particular site.

At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 2.7 mph. After the speed minder was removed, the mean speeds increased at sensor #2 by 2.9 mph. At the downstream sensor location (#3), the mean speeds decreased by 0.6 mph after the speed minder was implemented. The mean speeds increased by nearly 0.3 mph at the downstream sensor after the speed minder was removed. All statistical tests at sensor #2 were significant; however, the mean speed difference at sensor #3 was not statistically significant. These findings suggest that the speed minders were effective in reducing the mean speeds at the speed minder location while the device was in place and activated; however, the mean speeds increased after the speed minder was removed. The speeds increased to a level that was nearly equal to the speeds observed before the speed minder was implemented. These results are shown graphically in Figure A-6.

A.7 Route 879 Eastbound, Clearfield County

As noted in Table 4, the Route 879 site is located in Clearfield County. This route is a transition zone where the posted speed limit is 45 mph at the data collection location upstream of the speed minder site. The posted speed is 25 mph at the speed minder implementation point and at the data collection location 500 ft downstream of the speed minder implementation point. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-13. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-14. Figure A-7 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-13. Descriptive Statistics of Speeds at State Route 879 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	121	51.17	57.00	5.8982	81.8
	During	119	51.19	57.00	6.5137	81.5
	After	139	48.99	54.00	5.1591	78.4
2 At Speed Minder	Before	121	29.20	34.00	4.9542	76.9
	During	119	28.47	33.30	5.6386	74.8
	After	139	32.50	38.00	5.0063	94.2
3 500-ft Downstream Speed Minder	Before	121	27.77	33.30	4.7780	71.1
	During	119	28.86	33.00	4.1564	76.5
	After	139	30.20	35.00	4.9493	82.7

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 45 to 25 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would be lower than the speeds observed in the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

Table A-14. Statistical Tests of Mean Speed Differences for State Route 879.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	51.17	51.19	-0.02	0.980
	During - After	51.19	48.99	2.97	0.003
2	Before – During	29.20	28.47	1.06	0.288
	During - After	28.47	32.50	-6.02	0.000
3	Before – During	27.77	28.86	-1.89	0.060
	During - After	28.86	30.20	-2.36	0.019

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

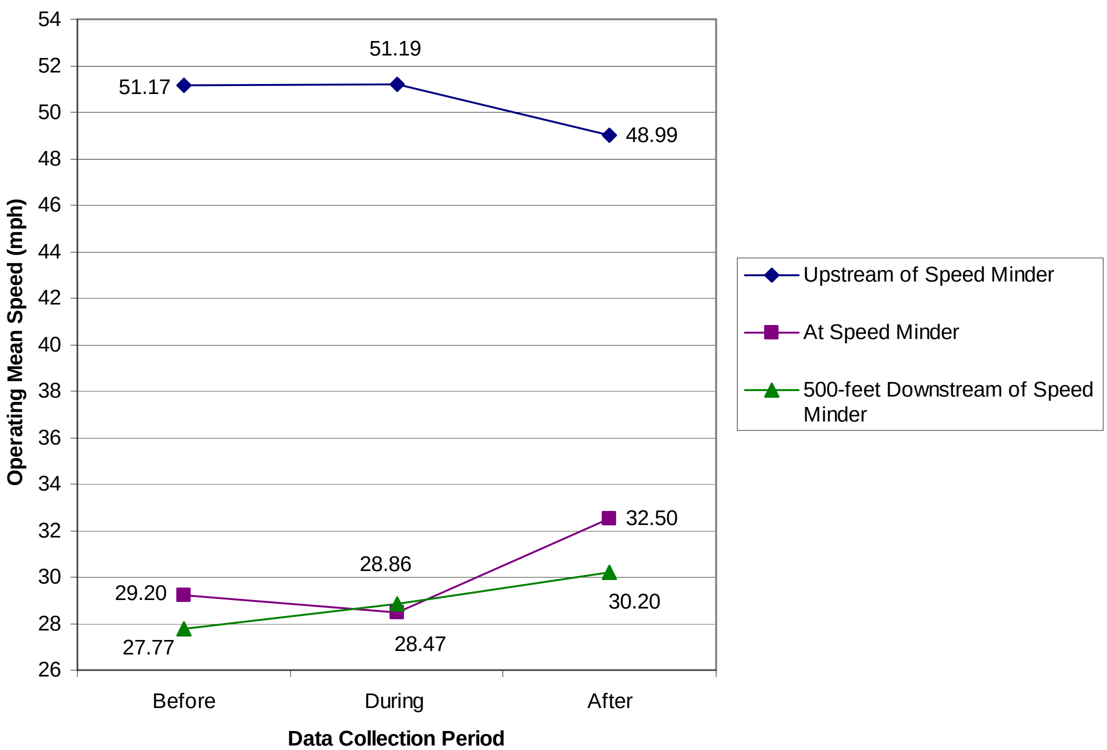

Figure A-7. Speed Profile Plot for State Route 879.

The t-tests shown in Table A-14 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing the before and during periods, but were different when comparing the during and after periods. As such, the speed reduction analysis presented in section 5.3 will provide a more accurate representation of the speed minder effect.

At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 0.7 mph; however, this result was not statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 4.0 mph, which was statistically significant. At the downstream sensor location (#3), the mean speeds increased by 1.1 mph after the speed minder was implemented; however, this increase was not statistically significant. The mean speeds increased by approximately 1.3 mph at the downstream sensor after the speed minder was removed when compared to the speeds observed while it was activated – this result was statistically significant. The effects of speed minder implementation at State Route 879 were nominal. These results are shown graphically in Figure A-7.

A.8 Route 56 Eastbound, Indiana County

As noted in Table 4, the Route 56 site is located in Indiana County. The posted speed limit is 55 mph along the entire study segment. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-15. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-16. Figure A-8 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-15. Descriptive Statistics of Speeds at State Route 56 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	96	46.96	57.75	10.4337	21.9
	During	99	43.81	58.00	13.0319	27.3
	After	89	41.79	55.00	12.3670	13.5
2 At Speed Minder	Before	96	48.40	58.00	9.6086	25.0
	During	99	39.40	53.00	12.0237	10.1
	After	89	41.03	55.80	12.6737	15.7
3 500-ft Downstream Speed Minder	Before	96	51.85	60.75	8.2206	35.4
	During	99	42.89	53.00	9.9948	11.1
	After	89	42.93	55.00	11.2278	14.6

Table A-16. Statistical Tests of Mean Speed Differences for State Route 56.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	46.96	43.81	1.87	0.064
	During - After	43.81	41.79	1.09	0.277
2	Before – During	48.40	39.40	5.78	0.000
	During - After	39.40	41.03	-0.90	0.368
3	Before – During	51.85	42.89	6.85	0.000
	During - After	42.89	42.93	-0.03	0.980

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

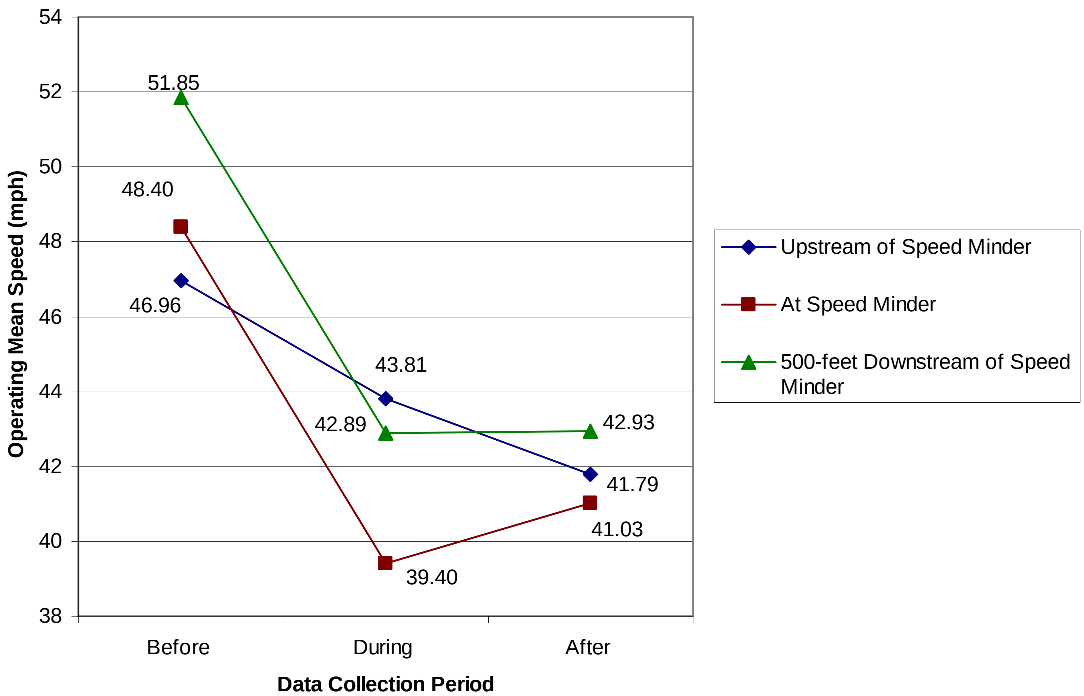

Figure A-8. Speed Profile Plot for State Route 56.

It was expected that the before, during, and after mean speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder implementation point along the study segment. It was also expected that the speeds at the speed minder point (sensor #2) would be equal to the observed mean speeds at the upstream location during the before period because the regulatory speed did not change along this study section. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds observed at sensor location #2.

The t-tests shown in Table A-16 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that, as expected, the difference in mean speeds at sensor #1 was not statistically significant when comparing the before and during, and during and after, time periods. As such, a true representation of the speed minder effect can be found by considering the difference in mean speeds before and during speed minder implementation at the speed minder implementation point. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 9.0 mph. This result was expected. After the speed minder was removed, the mean speeds increased at sensor #2 by 1.6 mph, which was not statistically significant. At the downstream sensor location (#3), the mean speeds decreased by 9.0 mph after the speed minder was implemented. The observed mean speeds remained almost constant at the downstream sensor after the speed minder was removed. These results are shown graphically in Figure A-8. The results of the statistically significant testing show that the speed minder was effective in reducing the observed mean operating speeds at this site. Additionally, the effects of the speed minder tended to remain for at least 1 week after the device was removed.

Of additional interest is the fact that speeds were higher at the downstream points than at the upstream point. This can be attributed to the vertical alignment of the site; sensor #1 is located near the crest of a vertical grade while sensors #2 and #3 are located after the end point of the crest curve, thus the high speeds are likely attributed to vertical grade along the section of roadway at the sensor #3 location. In addition, an additional speed minder, belonging to the municipality, was placed along the site between the before and during implementation periods. This could have led to the unusual speeds observed at this site.

A.9 Route 422 Westbound, Indiana County

As noted in Table 4, this particular Route 422 site is located in Indiana County (not to be confused with the site located in Armstrong County). The posted speed limit is 55 mph along the entire study segment. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-17. The statistical tests used to compare the mean speed before, during, and after speed minder implementation at each sensor location are shown in Table A-18. Figure A-9 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation at each sensor location.

Table A-17. Descriptive Statistics of Speeds at State Route 422 (Indiana County) Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	134	57.73	64.00	6.3117	64.2
	During	180	57.67	64.15	6.6566	63.3
	After	126	59.29	66.30	6.7493	70.6
2 At Speed Minder	Before	134	53.23	60.00	7.2898	35.8
	During	180	51.00	57.00	5.5753	21.1
	After	126	53.67	61.00	6.6525	37.3
3 500-ft Downstream Speed Minder	Before	134	53.87	59.05	6.1552	43.3
	During	180	50.88	57.00	6.2170	22.2
	After	126	53.71	61.00	7.0187	38.1

Table A-18. Statistical Tests of Mean Speed Differences for State Route 422 (Indiana County).

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	57.73	57.67	0.08	0.935
	During - After	57.67	59.29	-2.08	0.039
2	Before – During	53.23	51.00	2.96	0.003
	During - After	51.00	53.67	-3.69	0.000
3	Before – During	53.87	50.88	4.24	0.000
	During - After	50.88	53.71	-3.64	0.000
Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be equal to the observed mean speeds at the upstream location during the before period because the regulatory speed did not change along this study section. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds observed at sensor location #2.

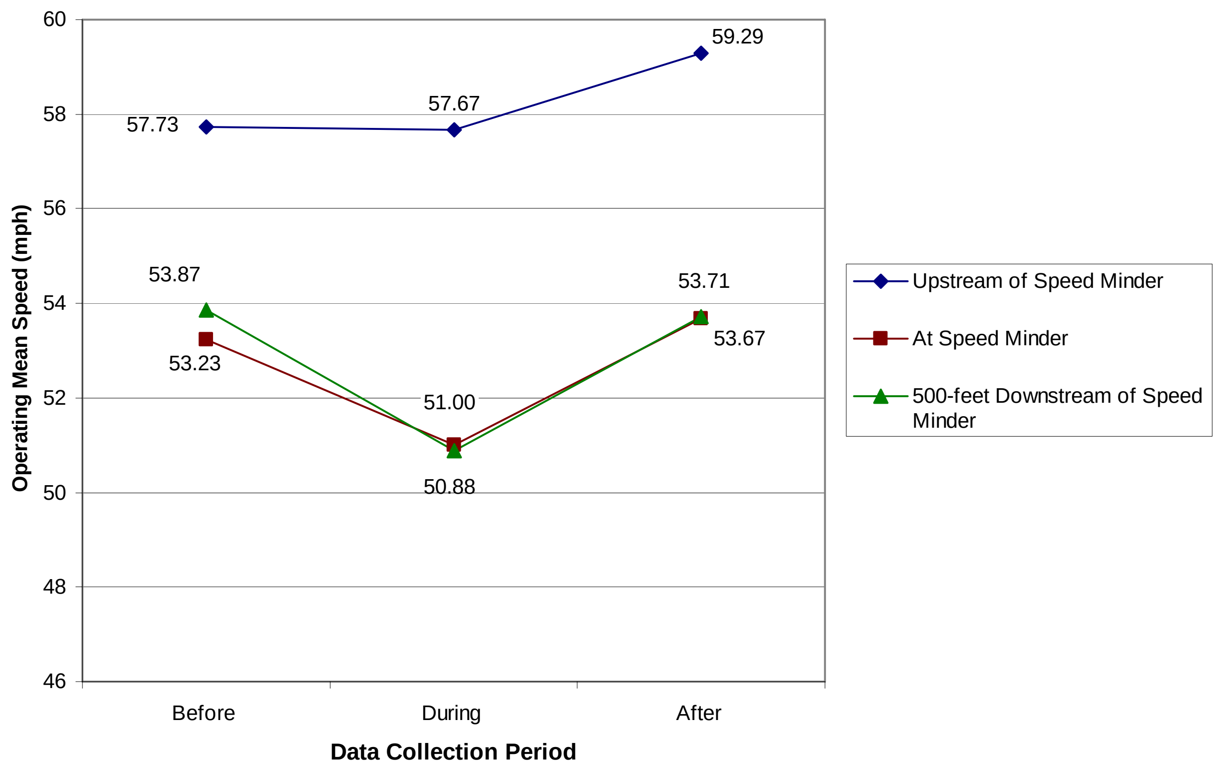

Figure A-9. Speed Profile Plot for State Route 422 (Indiana County).

The t-tests shown in Table A-18 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that, as expected, the difference in mean speeds at sensor #1 was not statistically significant when comparing the before and during periods; however, the mean speeds were approximately 1.6 mph higher in the after period when compared to the during period. As such, the analysis presented in section 5.3 will be more representative of the speed reduction attributable to the speed minder device.

At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 2.2 mph. This result was expected and statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 2.7 mph to a level that was approximately equal to the before data collection period. At the downstream sensor location (#3), the mean speeds decreased by 3.0 mph after the speed minder was implemented. The observed mean speeds then increased by approximately 2.8 mph 1 week after the speed minder was removed. These results are shown graphically in Figure A-9. The results of the statistical testing show that the speed minder was effective in reducing the observed mean operating speeds at this site; however, the speed reductions that resulted from the speed minder being activated did not remain 1 week after the device was removed. The nearly equal speeds at the speed minder location and at the location downstream of the speed minder in Figure A-9 suggest that motorists did comply with the reduced speed after passing the speed minder along this roadway segment.

A.10 Route 553 Westbound, Indiana County

As noted in Table 4, the Route 553 site is located in Indiana County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-19. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-20. Figure A-10 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-19. Descriptive Statistics of Speeds at State Route 553 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	129	48.00	55.00	7.1425	14.7
	During	186	48.53	55.00	6.4071	14.5
	After	141	48.47	55.00	6.5121	12.1
2 At Speed Minder	Before	129	47.26	54.80	7.5783	95.3
	During	186	39.35	46.00	6.5711	72.6
	After	141	47.17	53.00	5.8797	96.5
3 500-ft Downstream Speed Minder	Before	129	46.81	53.00	7.7933	95.3
	During	186	40.42	45.25	5.6480	83.9
	After	141	47.67	55.00	6.5066	98.6

Table A-20. Statistical Tests of Mean Speed Differences for State Route 553.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	48.00	48.53	-0.68	0.500
	During - After	48.53	48.47	0.08	0.934
2	Before – During	47.26	39.35	9.61	0.000
	During - After	39.35	47.17	-11.32	0.000
3	Before – During	46.81	40.42	7.97	0.000
	During - After	40.42	47.67	-10.56	0.000

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

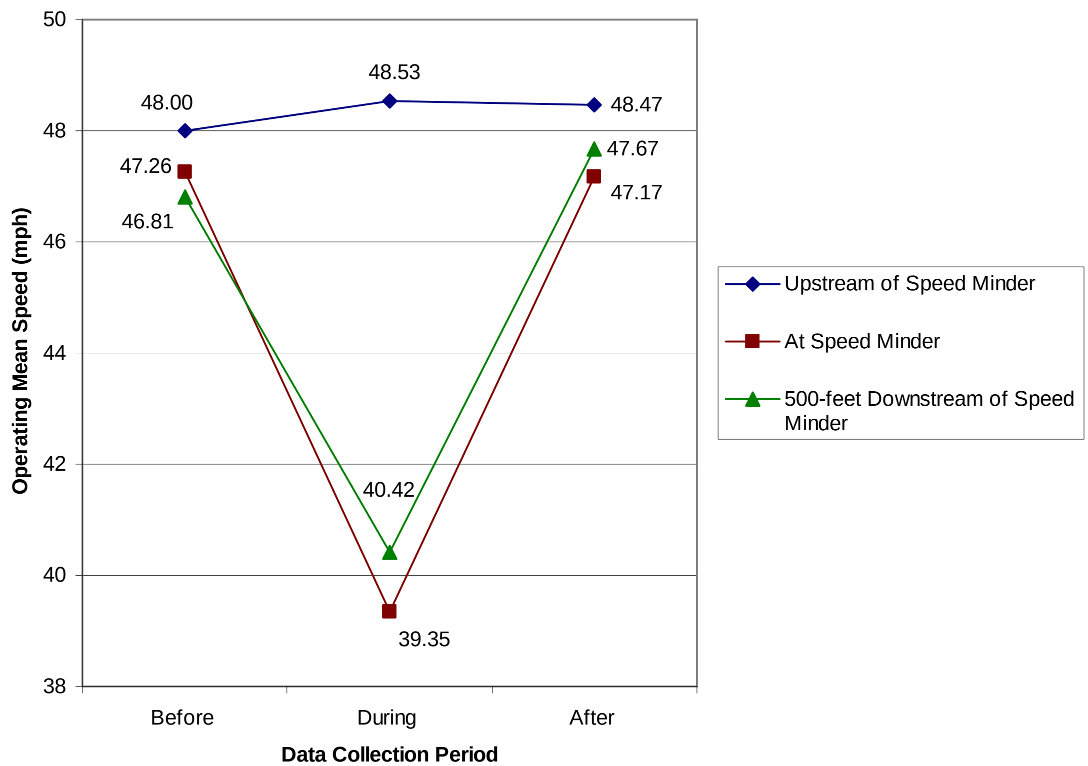

Figure A-10. Speed Profile Plot for State Route 553.

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

The t-tests shown in Table A-20 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. As expected, the results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing any of the successive data collection time periods. As such, the speed reduction observed at the speed minder implementation point is an accurate representation of the speed reduction observed by drivers at this study location. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 7.9 mph; this result was statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 7.8 mph, to a level that was nearly equal to the speed prior to implementing the speed minder. At the downstream sensor location (#3), the mean speeds decreased by 6.4 mph after the speed minder was implemented, but increased by 7.3 mph after the device was removed. These results are shown graphically in Figure A-10. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed. The nearly equal speeds at the speed minder location and at the location downstream of the speed minder in Figure A-10 suggest that motorists did comply with the reduced speed after passing the speed minder along this roadway segment.

A.11 Route 4422 Eastbound, Indiana County

As noted in Table 4, the Route 4422 site is located in Indiana County. The posted speed limit is 45 mph along the entire study segment. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-21. The statistical tests used to compare the mean speed before, during, and after speed minder implementation at each sensor location are shown in Table A-22. It should be noted that there were two during and two after data collection periods at the Route 4422 site to determine if the speed minders remained effective throughout the 2-week period of implementation. Figure A-11 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation at each sensor location.

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be equal to the observed mean speeds at the upstream location during the before period because the regulatory speed did not change along this study section. During the time that the speed minder was in place (two during periods), it was expected that the observed free-flow speeds would be lower in the first during period when compared to the before period, and then remain constant when comparing the two during data collection periods. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds observed at sensor location #2.

Table A-21. Descriptive Statistics of Speeds at State Route 4422 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	112	46.63	53.00	5.8987	57.1
	During 1	161	46.01	52.00	6.8324	49.7
	During 2	160	50.92	58.15	7.6725	77.5
	After 1	173	47.77	56.00	9.0215	65.3
	After 2	192	48.02	56.00	7.2559	63.5
2 At Speed Minder	Before	112	50.79	57.35	6.6920	79.5
	During 1	161	46.53	53.00	6.6446	55.9
	During 2	160	46.26	52.00	5.3535	49.4
	After 1	173	49.70	57.00	7.2779	73.4
	After 2	192	51.49	57.00	5.9659	85.9
3 500-ft Downstream Speed Minder	Before	112	49.94	56.00	5.8683	76.8
	During 1	161	46.33	52.00	6.4535	53.4
	During 2	160	45.69	51.00	5.1347	46.2
	After 1	173	47.92	54.00	6.0496	65.9
	After 2	192	49.25	55.00	5.6836	76.6

Table A-22. Statistical Tests of Mean Speed Differences for State Route 4422.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During 1	46.63	46.01	0.80	0.424
	During 1 – During 2	46.01	50.92	-6.05	0.000
	During 2 – After 1	50.92	47.77	3.44	0.001
	After 1 – After 2	47.77	48.02	-0.29	0.772
2	Before – During 1	50.79	46.53	5.19	0.000
	During 1 – During 2	46.53	46.26	0.40	0.689
	During 2 – After 1	46.26	49.70	-4.94	0.000
	After 1 – After 2	49.70	51.49	-2.55	0.011
3	Before – During 1	49.94	46.33	4.80	0.000
	During 1 – During 2	46.33	45.69	0.98	0.326
	During 2 – After 1	45.69	47.92	-3.64	0.000
	After 1 – After 2	47.92	49.25	-2.16	0.032

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

The t-tests shown in Table A-22 compare the mean speeds at each sensor location during all data collection periods. The results indicate that, as expected, the difference in mean speeds at sensor #1 was not statistically significant when comparing the before and first during periods; however, the mean speeds were higher during the second data collection period when compared to the first during period. The analysis presented in section 5.3 below will provide a more accurate representation of the speed minder effect at this site.

At the speed minder location, the mean speeds were lower in the first during period than in the before period by approximately 4.3 mph. This result was expected and statistically significant. During the second during period, the observed mean speeds were not statistically different from the speeds observed during the first during period. After the speed minder was removed, the mean speeds increased at sensor #2 by 3.4 mph. During the second after period, the mean speeds again increased by 1.8 mph. The mean speeds observed during the second after period were nearly equal to the mean speeds observed before the speed minder was implemented. At the downstream sensor location (#3), the mean speeds decreased by 3.6 mph after the speed minder was implemented. The observed speeds did not change significantly when comparing the second during period data to the first during period data. The observed mean speeds then increased by approximately 2.2 mph 1 week after the speed minder was removed, and then increased by 1.3 mph 2 weeks after the speed minder was removed. These results indicate that the speed minder was effective in reducing mean operating speeds while in place for 2 weeks; however, the speed reduction attributed to the speed minders did not remain in place after the speed minder was removed from the site. Speed profile plots of the observed mean speeds are shown in Figure A-11 for all data collection locations and time periods.

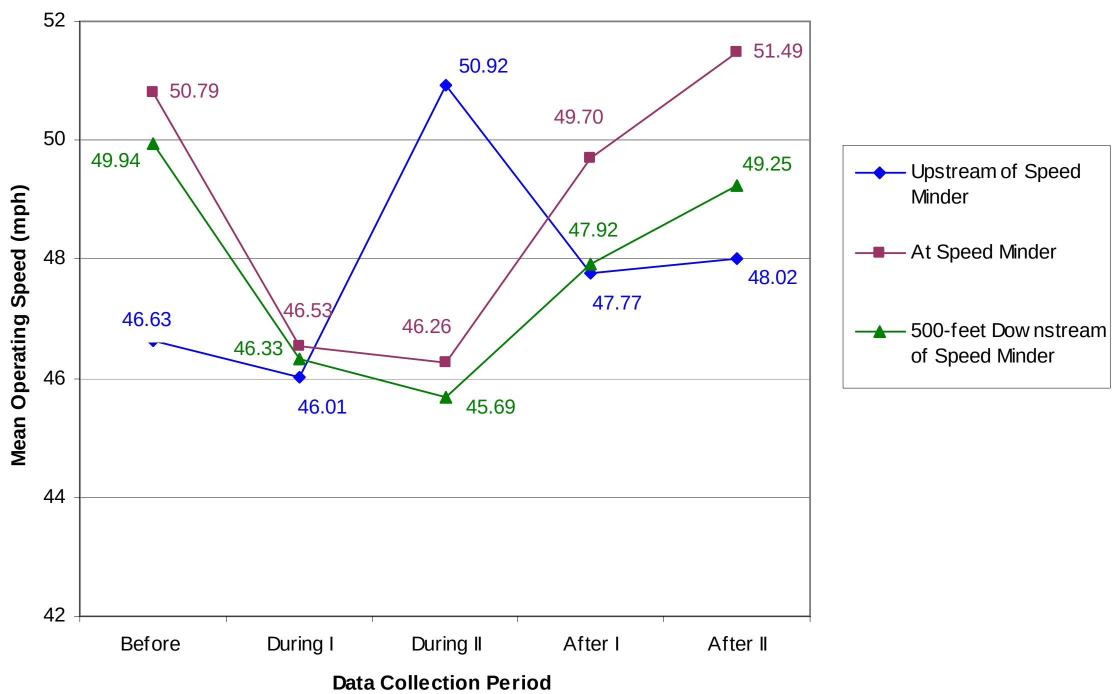

Figure A-11. Speed Profile Plot for State Route 4422.

Similarly to the previous Route 56 site, the speed profile plot at the Route 4422 site exhibited several unusual characteristics. At sensor #1, the combination of a lane reduction and the presence of a crest vertical curve likely resulted in lower speeds at this location than at the sensor #2 and #3 locations. During the second week of speed minder implementation (during II period in Figure A-11), the mean speed was significantly higher at sensor #1 when compared to other time periods. Although unexpected, a possible reason for this might be due to vehicles attempting to pass other vehicles in the lane merge area.

A.12 Route 3035 Northbound, Indiana County

As noted in Table 4, the Route 3035 site is located in Indiana County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-23. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-24. Figure A-12 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-23. Descriptive Statistics of Speeds at State Route 3035 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	111	39.56	47.00	7.9803	1.8
	During	107	37.65	48.00	9.0971	0.0
	After	104	38.23	44.55	5.9206	0.0
2 At Speed Minder	Before	111	36.42	42.00	5.1373	60.4
	During	107	31.79	37.00	4.9787	24.3
	After	104	37.66	43.00	5.6648	68.3
3 500-ft Downstream Speed Minder	Before	111	36.54	42.50	6.1345	59.5
	During	107	33.59	39.00	4.7064	29.9
	After	104	35.82	41.00	5.2819	53.8

Table A-24. Statistical Tests of Mean Speed Differences for State Route 3035.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	39.56	37.65	1.65	0.101
	During - After	37.65	38.23	-0.55	0.583
2	Before – During	36.42	31.79	6.76	0.000
	During - After	31.79	37.66	-7.99	0.000
3	Before – During	36.54	33.59	3.99	0.000
	During - After	33.59	35.82	-3.23	0.001
Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

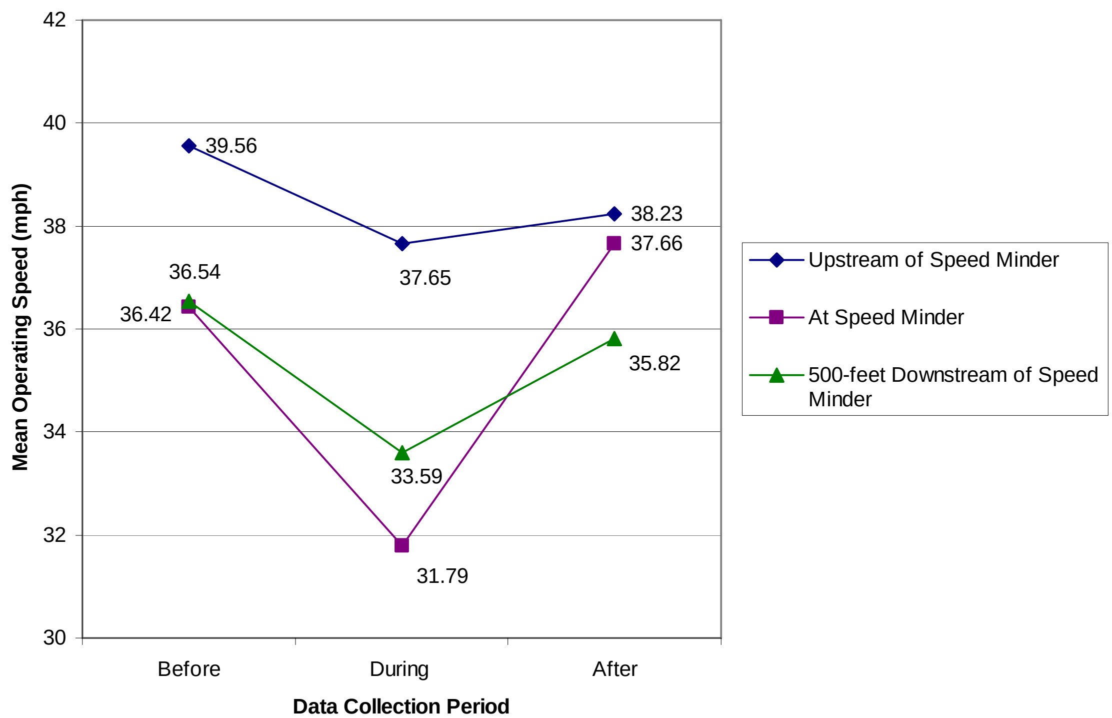

Figure A-12. Speed Profile Plot for State Route 3035.

The t-tests shown in Table A-24 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. As expected, the results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing any of the successive data collection time periods. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 4.6 mph; this result was statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 5.9 mph, to a level that was slightly higher than the speed prior to implementing the speed minder. At the downstream sensor location (#3), the mean speeds decreased by 3.0 mph after the speed minder was implemented, but increased by 2.2 mph after the device was removed. These results are shown graphically in Figure A-12. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed.

A.13 Route 110 Eastbound, Indiana County

As noted in Table 4, the Route 110 site is located in Indiana County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-25. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-26. It should be noted that there were two during and two after data collection time periods at this site to determine if the speed minder was effective in reducing mean operating speeds for a period of 2 consecutive weeks. Figure A-13 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-25. Descriptive Statistics of Speeds at State Route 110 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85th-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	152	56.69	62.35	6.4420	55.9
	During 1	143	56.01	63.00	6.5235	51.7
	During 2	128	56.04	65.00	7.3617	45.3
	After 1	156	55.12	62.00	7.4629	46.2
	After 2	100	56.22	64.00	7.4218	50.0
2 At Speed Minder	Before	152	46.81	52.00	6.5172	97.4
	During 1	143	41.20	48.00	6.7503	79.0
	During 2	128	42.88	50.00	6.9452	86.7
	After 1	156	46.73	53.00	6.4251	94.9
	After 2	100	47.59	54.15	6.7840	96.0
3 500-ft Downstream Speed Minder	Before	152	52.40	59.00	7.0526	100.0
	During 1	143	44.71	50.00	5.8825	97.9
	During 2	128	44.12	49.00	5.8976	95.3
	After 1	156	48.64	54.00	6.2258	97.4
	After 2	100	49.38	56.00	7.0220	99.0

Table A-26. Statistical Tests of Mean Speed Differences for State Route 110.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During 1	56.69	56.01	0.90	0.369
	During 1 – During 2	56.01	56.04	-0.04	0.972
	During 2 – After 1	56.04	55.12	1.04	0.299
	After 1 – After 2	55.12	56.22	-1.15	0.250
2	Before – During 1	46.81	41.20	7.25	0.000
	During 1 – During 2	41.20	42.88	-2.01	0.045
	During 2 – After 1	42.88	46.73	-4.81	0.000
	After 1 – After 2	46.73	47.59	-1.01	0.314
3	Before – During 1	52.40	44.71	10.19	0.000
	During 1 – During 2	44.71	44.12	0.82	0.411
	During 2 – After 1	44.12	48.64	-6.27	0.000
	After 1 – After 2	48.64	49.38	-0.86	0.391

Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

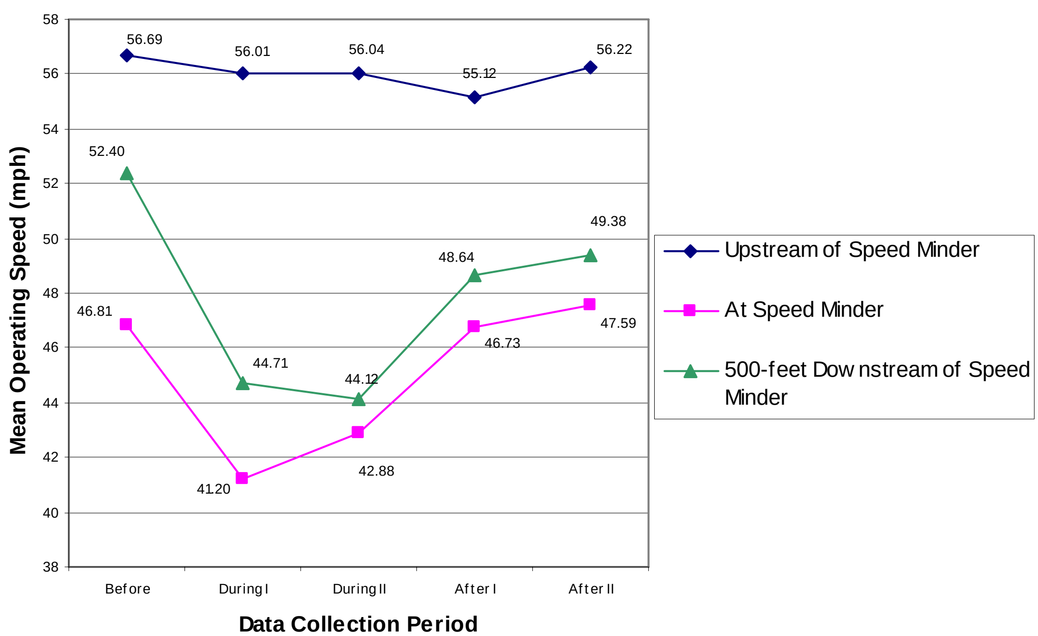

Figure A-13. Speed Profile Plot for State Route 110.

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

The t-tests shown in Table A-26 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. As expected, the results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing any of the successive data collection time periods. At the speed minder location, the mean speeds were lower in the first during period than in the before period by approximately 5.6 mph; this result was statistically significant. During the second during period, the mean speeds increased by 1.7 mph when compared to the first during period. After the speed minder was removed, the mean speeds increased at sensor #2 by 3.9 mph, to a level that was nearly equal to the speed prior to implementing the speed minder. During the second after data collection period, the mean speeds were slightly higher than both the before and the first after period. At the downstream sensor location (#3), the mean speeds decreased by 7.7 mph after the speed minder was implemented and remained nearly constant during the second during period. After the speed minder was removed, observed mean speeds increased by 4.5 mph during the first week. During the second after period, the observed mean speeds were nearly equal to the mean speeds observed during the first after period. These results are shown graphically in Figure A-13. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed.

A.14 Route 422 Eastbound, Armstrong County

As noted in Table 4, there is a second study site along Route 422, but located in Armstrong County. The posted speed limit is 55 mph along the entire study segment. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-27. The statistical tests used to compare the mean speed before, during, and after speed minder implementation at each sensor location are shown in Table A-28. Figure A-14 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation at each sensor location.

Table A-27. Descriptive Statistics of Speeds at State Route 422 (Armstrong County) Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed mph)	Standard Deviation of Speed mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	150	56.48	64.00	6.8598	54.7
	During	109	57.04	62.80	6.4778	56.9
	After	142	54.99	62.00	7.1225	48.6
2 At Speed Minder	Before	150	59.00	64.65	5.8425	76.7
	During	109	55.77	61.00	5.2593	53.2
	After	142	58.68	65.00	6.0146	70.4
3 500-ft Downstream Speed Minder	Before	150	52.49	59.65	8.6813	33.3
	During	109	49.99	56.00	6.3850	16.5
	After	142	52.04	58.00	6.5172	30.3

Table A-28. Statistical Tests of Mean Speed Differences for State Route 422 (Armstrong County).

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	56.48	57.04	-0.67	0.504
	During - After	57.04	54.99	2.38	0.018
2	Before – During	59.00	55.77	4.66	0.000
	During - After	55.77	58.68	-4.08	0.000
3	Before – During	52.49	49.99	2.67	0.008
	During - After	49.99	52.04	-2.50	0.013
Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be equal to the observed mean speeds at the upstream location during the before period because the regulatory speed did not change along this study section. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds observed at sensor location #2.

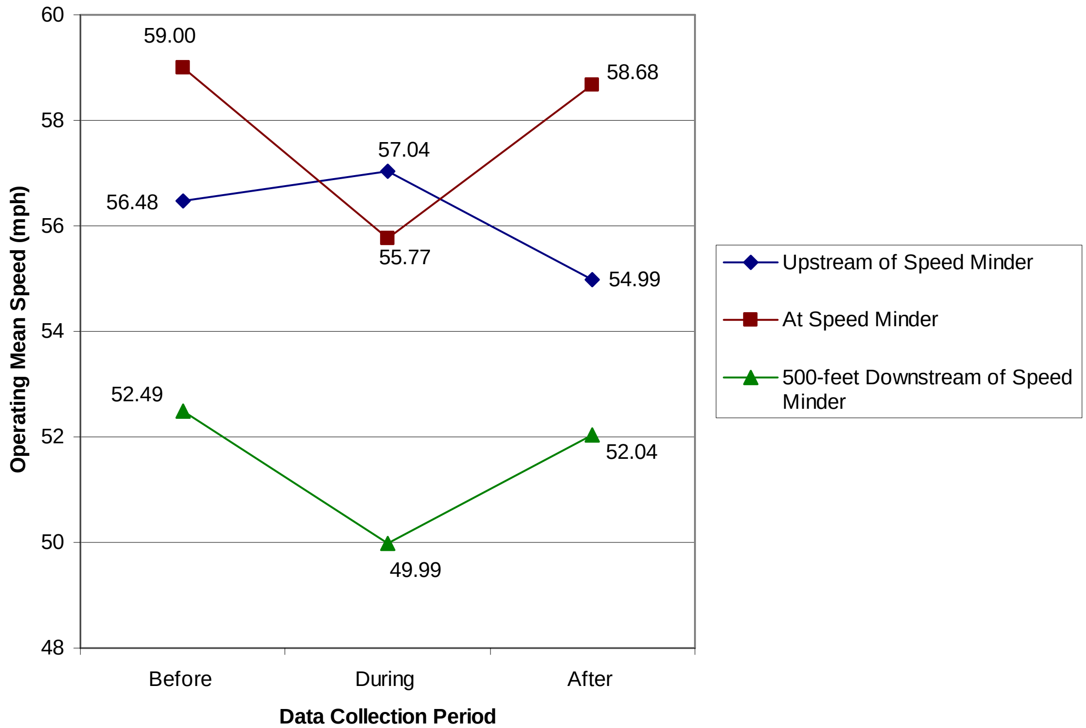

Figure A-14. Speed Profile Plot for State Route 422 (Armstrong County).

The t-tests shown in Table A-28 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that, as expected, the difference in mean speeds at sensor #1 was not statistically significant when comparing the before and during periods; however, the mean speeds were approximately 2.0 mph lower in the after period when compared to the during period. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 3.2 mph. This result was expected and statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 2.9 mph to a level that was approximately equal to the before data collection period. At the downstream sensor location (#3), the mean speeds decreased by 2.5 mph after the speed minder was implemented. The observed mean speeds then increased by approximately 2.0 mph 1 week after the speed minder was removed. These results are shown graphically in Figure A-14. The results of the statistical testing show that the speed minder was effective in reducing the observed mean operating speeds at this site; however, the speed reductions that resulted from the speed minder being activated did not remain after the device was removed.

A.15 Route 356 Northbound, Butler County

As noted in Table 4, the Route 356 site is located in Butler County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 40 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-29. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-30. Figure A-15 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-29. Descriptive Statistics of Speeds at State Route 356 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed mph)	Standard Deviation of Speed mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	148	51.35	57.00	6.4258	22.3
	During	243	52.62	59.00	6.5148	26.3
	After	182	52.01	58.85	6.4079	26.9
2 At Speed Minder	Before	148	49.16	55.00	5.9694	92.6
	During	243	43.79	48.00	4.7793	75.7
	After	182	49.13	55.00	6.0368	92.9
3 500-ft Downstream Speed Minder	Before	148	48.21	53.00	5.6040	91.2
	During	243	44.77	50.00	7.2273	73.7
	After	182	47.17	53.00	5.6381	87.9

Table A-30. Statistical Tests of Mean Speed Differences for State Route 356.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	51.35	52.53	-1.89	0.060
	During - After	52.53	52.01	0.96	0.336
2	Before – During	49.16	43.64	9.28	0.000
	During - After	43.64	49.13	-9.84	0.000
3	Before – During	48.21	44.66	5.26	0.000
	During - After	44.66	47.17	-3.84	0.000
Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 40 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

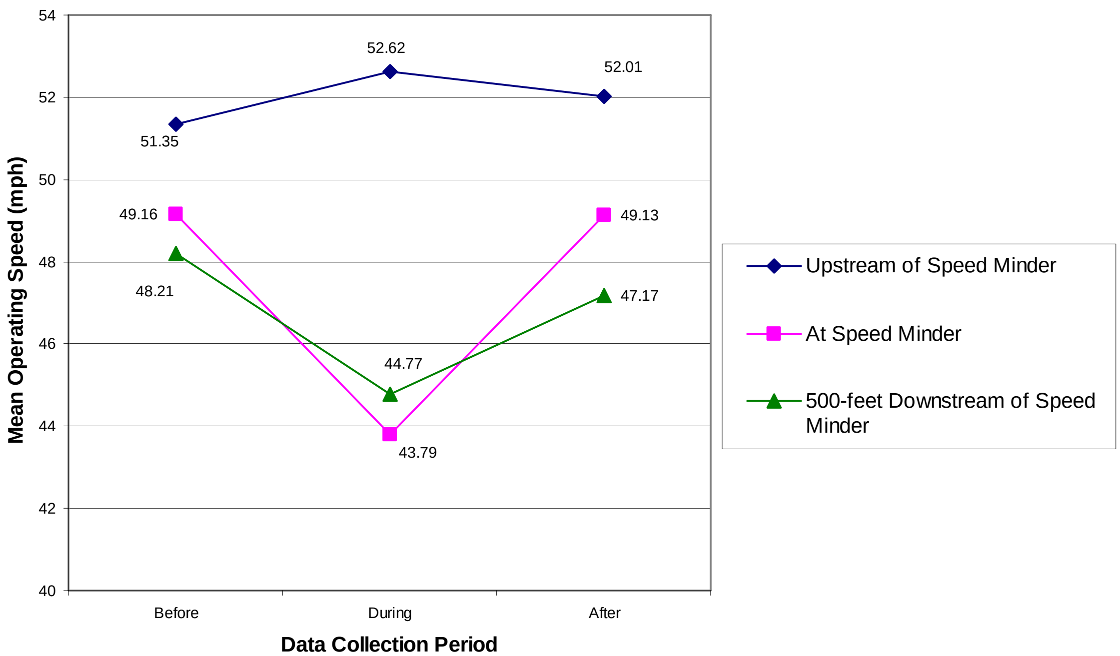

Figure A-15. Speed Profile Plot for State Route 356.

The t-tests shown in Table A-30 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. As expected, the results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing any of the successive data collection time periods. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 5.5 mph; this result was statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 5.5 mph, to a level that was nearly equal to the speed prior to implementing the speed minder. At the downstream sensor location (#3), the mean speeds decreased by 3.6 mph after the speed minder was implemented, but increased by 2.5 mph after the device was removed. These results are shown graphically in Figure A-15. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed.

A.16 Route 66 Southbound, Armstrong County

As noted in Table 4, the Route 66 site is located in Armstrong County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 40 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-31. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-32. Figure A-16 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-31. Descriptive Statistics of Speeds at State Route 66 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85^{th}-percentile Speed (mph)	Standard Deviation of Speed (mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	173	52.27	58.00	5.4259	26.6
	During	172	50.87	57.00	6.2003	19.8
	After	172	49.21	54.00	5.2574	11.0
2 At Speed Minder	Before	173	42.46	49.00	5.2579	60.7
	During	172	38.91	44.00	5.6229	41.3
	After	172	43.14	49.00	5.1533	67.4
3 500-ft Downstream Speed Minder	Before	173	41.89	48.00	6.4280	60.7
	During	172	38.66	43.40	5.4604	34.3
	After	172	45.16	52.00	6.5099	78.5

Table A-32. Statistical Tests of Mean Speed Differences for State Route 66.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	52.27	50.87	2.23	0.026
	During - After	50.87	49.21	2.68	0.008
2	Before – During	42.46	38.91	6.06	0.000
	During - After	38.91	43.14	-7.27	0.000
3	Before – During	41.89	38.66	5.03	0.000
	During - After	38.66	45.16	-10.03	0.000

Notes: All statistical tests were two-sided (H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0)
* mean speed difference is statistically significant at $\alpha = 0.05$

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 40 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

The t-tests shown in Table A-32 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. The results indicate that the difference in mean speeds at sensor #1 was statistically significant when comparing successive data collection time periods. The mean operating speeds decreased by 1.4 mph when the speed minder was implemented and then decreased by an additional 1.6 mph after the speed minder was removed from the site. This result was not expected. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 3.6 mph; this result was statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 4.1 mph, to a level that was slightly higher than mean speeds observed prior to implementing the speed minder. At the downstream sensor location (#3), the mean speeds decreased by 3.2 mph after the speed minder was implemented, but increased by 6.5 mph after the device was removed. These results are shown graphically in Figure A-16. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed.

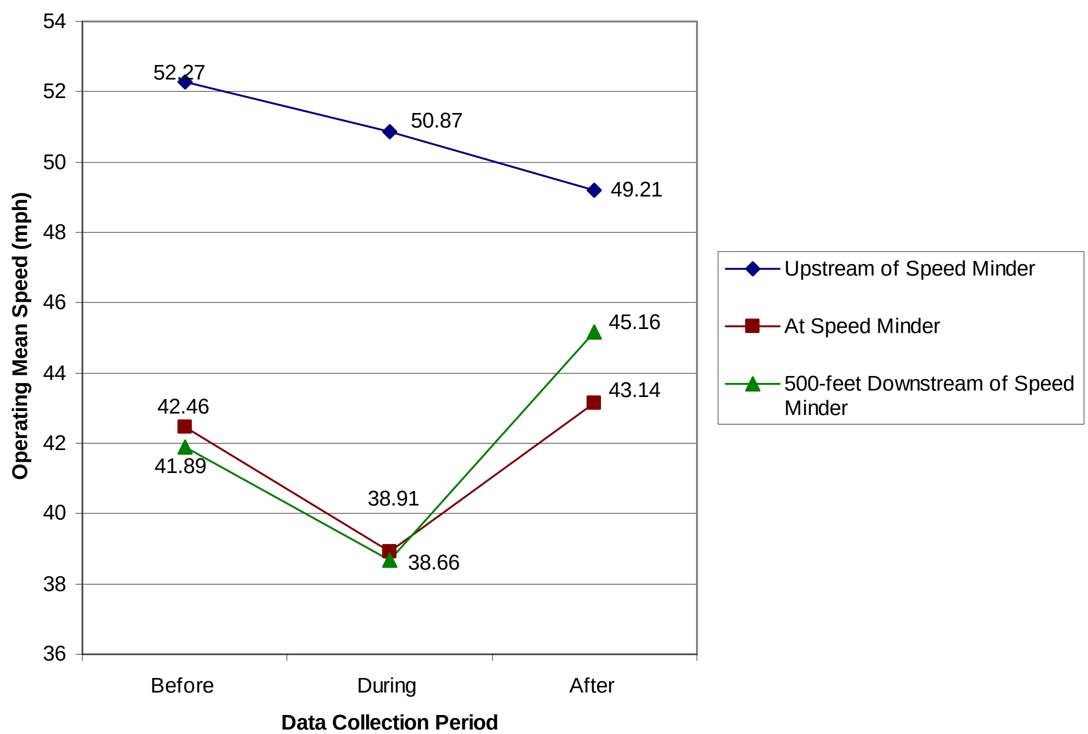

Figure A-16. Speed Profile Plots for State Route 66.

A.17 Route 322 Westbound, Jefferson County

As noted in Table 4, the Route 322 site is located in Jefferson County. This route is a transition zone where the posted speed limit is 55 mph at the data collection location upstream of the speed minder site. The posted speed is 35 mph at the speed minder site and at the data collection location 500 ft downstream of the speed minder site. The descriptive statistics of observed, free-flow passenger car speeds are shown in Table A-33. The statistical tests used to compare the mean speed before, during, and after speed minder implementation are shown in Table A-34. Figure A-17 is a graphical illustration of the mean operating speeds at each data collection location before, during, and after speed minder implementation.

Table A-33. Descriptive Statistics of Speeds at State Route 322 Location.

Sensor	Time Period	Sample Size	Mean Speed (mph)	85th-percentile Speed mph)	Standard Deviation of Speed mph)	Percent Exceeding Posted Speed Limit
1 Upstream of Speed Minder	Before	99	51.17	56.30	5.8398	18.2
	During	143	51.94	57.00	5.7338	24.5
	After	186	51.68	58.00	6.5224	27.4
2 At Speed Minder	Before	99	43.13	49.30	6.1688	92.9
	During	143	36.36	40.00	4.6927	50.3
	After	186	44.42	51.25	6.8755	89.8
3 500-ft Downstream Speed Minder	Before	99	39.95	45.00	5.6863	79.8
	During	143	35.06	39.00	4.5474	43.4
	After	186	41.39	48.00	6.2047	81.7

Table A-34. Statistical Tests of Mean Speed Differences for State Route 322.

Sensor	Comparison Test	Before Mean Speed	After Mean Speed	t-statistic	p-value
1	Before – During	51.17	51.94	-1.02	0.311
	During - After	51.94	51.68	0.38	0.701
2	Before – During	43.13	36.36	9.23	0.000
	During - After	36.36	44.42	-12.62	0.000
3	Before – During	39.95	35.06	7.12	0.000
	During - After	35.06	41.39	-10.68	0.000
Notes: All statistical tests were two-sided H_o: $\mu_1 - \mu_2 = 0$; H_a: $\mu_1 - \mu_2$ K 0) * mean speed difference is statistically significant at $\alpha = 0.05$					

It was expected that the before, during, and after speeds would be nearly equal at sensor #1, which was placed upstream of the speed minder site along the study segment. It was also expected that the speeds at the speed minder location (sensor #2) would be lower than the speeds at the upstream location during the before period because this site is a transition zone where the regulatory speed changes from 55 to 35 mph. During the time that the speed minder was in place (during period), it was expected that the observed free-flow speeds would decrease when compared to the before period. At the downstream sensor location (#3), it was hypothesized that the observed speeds would be nearly equal to the speeds at sensor location #2.

The t-tests shown in Table A-34 compare the mean speeds at each sensor location before and during, and during and after, speed minder implementation. As expected, the results indicate that the difference in mean speeds at sensor #1 was not statistically significant when comparing any of the successive data collection time periods. At the speed minder location, the mean speeds were lower in the during period than in the before period by approximately 6.8 mph; this result was statistically significant. After the speed minder was removed, the mean speeds increased at sensor #2 by 8.1 mph, to a level that was higher than the mean speed prior to implementing the speed minder. At the downstream sensor location (#3), the mean speeds decreased by 4.9 mph after the speed minder was implemented, but increased by 6.3 mph after the device was removed. These results are shown graphically in Figure A-17. The statistical tests indicate that the speed minder was effective in reducing the observed mean speed of passenger cars while in place and activated; however, the effect did not remain after the speed minder was removed.

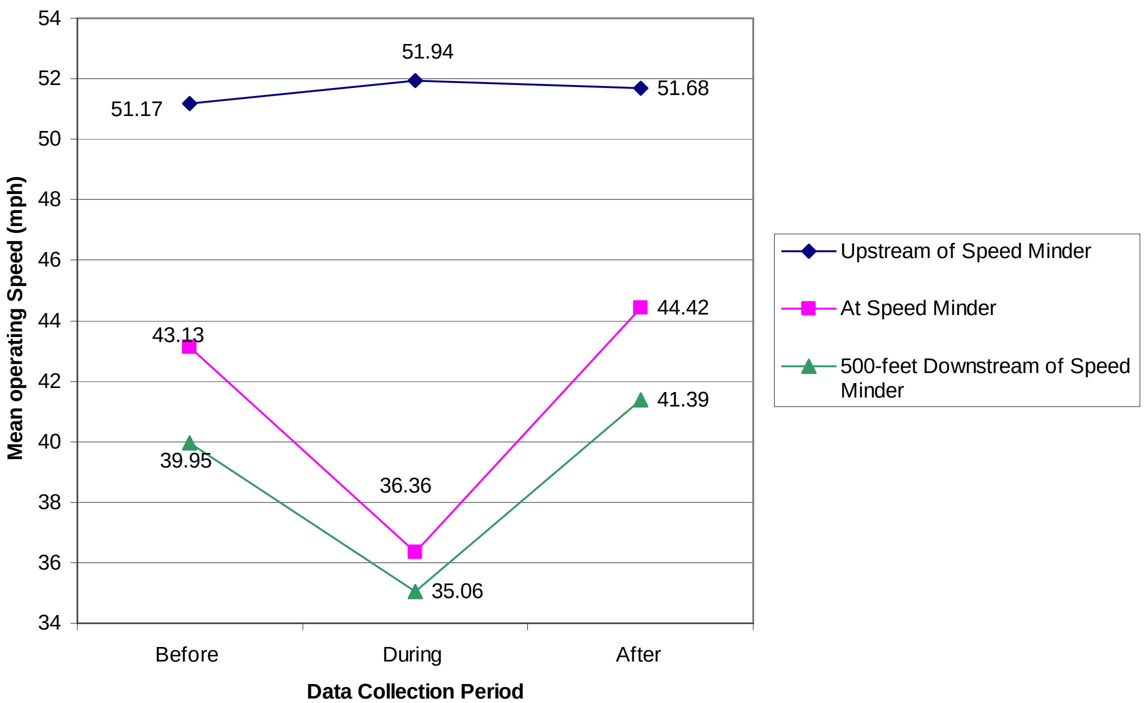

Figure A-17. Speed Profile Plot for State Route 322.

A.18 Summary of Individual Site Point Speed Analysis

The purpose of the analysis presented above for each individual site was to compare the mean observed speeds at each sensor location before, during, and after speed minder implementation at all 17 data collection sites. The results indicate that the speed minder was generally effective in reducing mean passenger car operating speeds at each site while the device was in place and activated; however, the observed speeds generally increased to the pre-speed-minder levels 1 week after the device was removed from the site. Although the point-by-point speed data presented above do provide some preliminary information related to speed minder effectiveness, a true representation of the speed reductions generated by the device can only be precisely determined when considering the speed differential between successive data collection points during successive time periods. Because the analysis results presented earlier do not take into consideration the speed change between successive point speed locations, and because the observed speeds at the upstream sensor location changed at several locations, the speed reduction effects attributed to the speed minder may be either over- or under-estimated. As such, the following section of this report considers the speed change between successive data collection points. The same analysis methodology that was used in the previous section is used again in the next section to determine the true effect of the speed reduction that can be attributed to the speed minder at all 17 data collection sites.

APPENDIX B
Tests for the Proportions of Vehicles Exceeding the Posted Speed Limit

Table B-1. Statistical Tests of Proportions for Exceeding Vehicles for Route 550 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	36.9	51.6	-2.48	0.013
	During - After	51.6	34.3	2.83	0.005
2	Before – During	71.3	23.2	9.04	0.000
	During - After	23.2	65.7	-7.40	0.000
3	Before – During	41.0	23.2	3.17	0.002
	During - After	23.2	36.2	-2.24	0.025

Table B-2. Statistical Tests of Proportions for Exceeding Vehicles for Route 192 (Segments 0270-0290) Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	43.2	47.5	-0.60	0.546
	During - After	47.5	59.0	-1.67	0.096
2	Before – During	96.8	81.8	3.52	0.000
	During - After	81.8	97.1	-3.65	0.000
3	Before – During	97.9	79.8	4.21	0.000
	During - After	79.8	98.1	-4.31	0.000

Table B-3. Statistical Tests of Proportions for Exceeding Vehicles for Route 192 (Segments 0210-0220) Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	43.4	72.7	-3.36	0.001
	During - After	72.7	82.3	-1.42	0.155
2	Before – During	69.8	28.8	4.87	0.000
	During - After	28.8	69.8	-5.63	0.000
3	Before – During	77.4	68.2	1.13	0.258
	During - After	68.2	80.2	-1.71	0.087

Table B-4. Statistical Tests of Proportions for Exceeding Vehicles for Route 53 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During 1	55.6	43.7	1.66	0.097
	During 1 – During 2	43.7	37.6	1.06	0.289
	During 2 – After 1	37.6	39.0	-0.29	0.774
	After 1 – After 2	39.0	45.6	-1.33	0.184
2	Before – During 1	95.1	75.6	4.21	0.000
	During 1 – During 2	75.6	80.9	-1.09	0.274
	During 2 – After 1	80.9	98.0	-5.74	0.000
	After 1 – After 2	98.0	97.4	0.43	0.669
3	Before – During 1	91.4	81.5	2.08	0.038
	During 1 – During 2	81.5	85.1	-0.81	0.419
	During 2 – After 1	85.1	95.6	-3.60	0.000
	After 1 – After 2	95.6	95.9	-0.12	0.904

Table B-5. Statistical Tests of Proportions for Exceeding Vehicles for Route 3040 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During 1	67.3	36.5	3.46	0.001
	During 1 – During 2	36.5	45.2	-1.16	0.245
	During 2 – After 1	45.2	58.2	-1.91	0.056
	After 1 – After 2	58.2	41.7	2.22	0.026
2	Before – During 1	84.6	50.8	4.20	0.000
	During 1 – During 2	50.8	42.9	1.03	0.302
	During 2 – After 1	42.9	86.8	-7.77	0.000
	After 1 – After 2	86.8	88.1	-0.26	0.798
3	Before – During 1	86.5	61.9	3.18	0.001
	During 1 – During 2	61.9	52.4	1.26	0.208
	During 2 – After 1	52.4	79.1	-4.34	0.000
	After 1 – After 2	79.1	88.1	-1.62	0.105

Table B-6. Statistical Tests of Proportions for Exceeding Vehicles for Route 453 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	34.3	45.7	-1.63	0.104
	During - After	45.7	54.8	-1.36	0.175
2	Before – During	63.6	46.8	2.38	0.017
	During - After	46.8	74.1	-4.27	0.000
3	Before – During	81.8	70.2	1.90	0.057
	During - After	70.2	69.6	0.09	0.925

Table B-7. Statistical Tests of Proportions for Exceeding Vehicles for Route 879 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	81.8	81.5	0.06	0.951
	During - After	81.5	78.4	0.62	0.535
2	Before – During	76.9	74.8	0.37	0.708
	During - After	74.8	94.2	-4.38	0.000
3	Before – During	71.1	76.5	-0.95	0.341
	During - After	76.5	82.7	-1.24	0.214

Table B-8. Statistical Tests of Proportions for Exceeding Vehicles for Route 56 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	21.9	27.3	-0.88	0.380
	During - After	27.3	13.5	2.40	0.017
2	Before – During	25.0	10.1	2.78	0.005
	During - After	10.1	15.7	-1.15	0.251
3	Before – During	35.4	11.1	4.18	0.000
	During - After	11.1	14.6	-0.71	0.475

Table B-9. Statistical Tests of Proportions for Exceeding Vehicles for Route 422 (Indiana County) Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	64.2	63.3	0.15	0.877
	During - After	63.3	70.6	-1.35	0.178
2	Before – During	35.8	21.1	2.86	0.004
	During - After	21.1	37.3	-3.07	0.002
3	Before – During	43.3	22.2	3.99	0.000
	During - After	22.2	38.1	-2.98	0.003

Table B-10. Statistical Tests of Proportions for Exceeding Vehicles for Route 553 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	14.7	14.5	0.05	0.958
	During - After	14.5	12.1	0.65	0.514
2	Before – During	95.3	72.6	6.06	0.000
	During - After	72.6	96.5	-6.59	0.000
3	Before – During	95.3	83.9	3.51	0.000
	During - After	83.9	98.6	-5.12	0.000

Table B-11. Statistical Tests of Proportions for Exceeding Vehicles for State Route 4422 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During 1	57.1	49.7	1.22	0.223
	During 1 – During 2	49.7	77.5	-5.41	0.000
	During 2 – After 1	77.5	65.3	2.49	0.013
	After 1 – After 2	65.3	63.5	0.35	0.723
2	Before – During 1	79.5	55.9	4.31	0.000
	During 1 – During 2	55.9	49.4	1.17	0.241
	During 2 – After 1	49.4	73.4	-4.63	0.000
	After 1 – After 2	73.4	85.9	-2.99	0.003
3	Before – During 1	76.8	53.4	4.17	0.000
	During 1 – During 2	53.4	46.2	1.29	0.198
	During 2 – After 1	46.2	65.9	-3.68	0.000
	After 1 – After 2	65.9	76.6	-2.26	0.024

Table B-12. Statistical Tests of Proportions for Exceeding Vehicles for Route 3035 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	1.8	0.0	1.43	0.154
	During - After	0.0	0.0	*	*
2	Before – During	60.4	24.3	5.79	0.000
	During - After	24.3	68.3	-7.13	0.000
3	Before – During	59.5	29.9	4.60	0.000
	During - After	29.9	53.8	-3.63	0.000

Table B-13. Statistical Tests of Proportions for Exceeding Vehicles for State Route 110 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During 1	55.9	51.7	0.72	0.472
	During 1 – During 2	51.7	45.3	1.06	0.289
	During 2 – After 1	45.3	46.2	-0.14	0.887
	After 1 – After 2	46.2	50.0	-0.60	0.548
2	Before – During 1	97.4	79.0	5.03	0.000
	During 1 – During 2	79.0	86.7	-1.70	0.090
	During 2 – After 1	86.7	94.9	-2.34	0.019
	After 1 – After 2	94.9	96.0	-0.43	0.669
3	Before – During 1	100.0	97.9	1.75	0.080
	During 1 – During 2	97.9	95.3	1.17	0.243
	During 2 – After 1	95.3	97.4	-0.94	0.347
	After 1 – After 2	97.4	99.0	-0.97	0.331

Table B-14. Statistical Tests of Proportions for Exceeding Vehicles for Route 422 (Armstrong County) Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	54.7	56.9	-0.35	0.723
	During - After	56.9	48.6	1.31	0.190
2	Before – During	76.7	53.2	3.98	0.000
	During - After	53.2	70.4	-2.81	0.005
3	Before – During	33.3	16.5	3.21	0.001
	During - After	16.5	30.3	-2.62	0.009

Table B-15. Statistical Tests of Proportions for Exceeding Vehicles for Route 356 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	22.3	26.3	-0.91	0.363
	During - After	26.3	26.9	-0.14	0.893
2	Before – During	92.6	75.7	4.82	0.000
	During - After	75.7	92.9	-5.12	0.000
3	Before – During	91.2	73.7	4.80	0.000
	During - After	73.7	87.9	-4.42	0.000

Table B-16. Statistical Tests of Proportions for Exceeding Vehicles for Route 66 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	26.6	19.8	1.51	0.132
	During - After	19.8	11.0	2.26	0.024
2	Before – During	60.7	41.3	3.68	0.000
	During - After	41.3	67.4	-5.05	0.000
3	Before – During	60.7	34.3	5.09	0.000
	During - After	34.3	78.5	-9.23	0.000

Table B-17. Statistical Tests of Proportions for Exceeding Vehicles for Route 322 Location.

Sensor	Comparison Test	Percentage Exceeding Before	Percentage Exceeding After	Z-statistic	p-value
1	Before – During	18.2	24.5	-1.19	0.234
	During - After	24.5	27.4	-0.61	0.545
2	Before – During	92.9	50.3	8.67	0.000
	During - After	50.3	89.8	-8.33	0.000
3	Before – During	79.8	43.4	6.30	0.000
	During - After	43.4	81.7	-7.64	0.000