



A Report from the University of Vermont Transportation Research Center

# Work Zones and Travel Speeds:

The Effects of Uniform Traffic Officers &  
Other Speed Management Measures

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## **ii. Disclaimer**

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the UVM Transportation Research Center. This report does not constitute a standard, specification, or regulation.

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# 1. Introduction

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Improving safety conditions in work zones, for both the workers as well as the travelers, is a major national concern, especially in light of the country's aging transportation infrastructure that requires increasing amount of maintenance, repair, and reconstruction work. Identified as one of twenty-two goals in the AASHTO Strategic Highway Safety Plan (SHSP), the improvement of work zone safety can include a variety of strategies targeted towards different emphasis areas (Antonucci et al. 2005). One such area is to increase driver compliance with work zone traffic controls, which may involve the following strategies:

- Enhance enforcement of work zone traffic laws;
- Improve credibility of signs; and
- Better application of increased driver penalties in work zones.

The focus of this research project will be on the first strategy, with a specific emphasis on the effects of Uniform Traffic Officers (UTO) and other speed management measures on driver compliance with reduced work zone speed limits. For the purpose of this study, UTO are police officers contracted for construction projects where the road remains open to travelers. The officers are stationed in marked police vehicles with the blue lights flashing and parked within project work zones while road workers are active. Typically, UTO remain inside the police vehicles but sometimes they may be on the roadway to help direct traffic, especially when temporary lane closures are needed or interactions are expected between road workers or construction equipment and the parts of the road that are open to the public. UTO do not normally perform enforcement duties and are used primarily for their presence. The use of police officers for various forms of enforcement for speeding and other moving violations is different from the use of UTO and considered as one of the other speed management measures in this project.

The goal of this work is to assess the effectiveness of UTO and other interventions on maintaining safe travel speeds and to help guide the Vermont Agency of Transportation (VAOT) in the provision of proper resource allocation for improving work zone safety.

## 1.1 Background

Analysis of Vermont crash data by the University of Vermont (UVM) Transportation Research Center (TRC) revealed that for the years 2003 through 2008, there was an average of 64 crash incidents per year that occurred in work zones. Of the total 385 work zone crashes reported in this six-year period, one case in 2003 included fatalities (there were two deaths in that case), while 65 cases involved other forms of injuries (for 91 people), and the remaining 319 incidents concerned property damage only. There are, however, great variations between the numbers of incidents over the years; the largest non-fatal injury tally in work zones was in 2003 with a count of 32 people and the smallest was in 2007 with only three. These fluctuations may be a

function of different factors, such as the amount of work activities conducted on the state's roadway each year, but it is also likely due to the small sample effect. Crashes are statistically rare events relative to population exposures; for example, the crash fatality rate in Vermont was 1.00 per 100 million vehicle miles traveled for 2008 (FARS 2011). In order to get a better perspective of this work zone safety problem, it is useful to review some national statistics.

In 2009, the Fatality Analysis Reporting System recorded 667 people across the United States who died in roadway work zones (FARS 2011). Of the 582 crashes that resulted in these deaths, speeding was identified as a primary contributing factor to 178 crashes, or more than 30% (FARS 2011). In addition, about 50,000 people are injured in work zones nationally each year, which is roughly equivalent to one injury every 10 minutes (NCHRP 2005). Considering both fatal and non-fatal crashes, around 60% occur on non-interstate roads posted for 55mph or higher (NCHRP 2005), making high speeds a significant concern in work zone traffic control.

## **1.2 Project Objectives**

This research project focuses on enhancing the effectiveness of work zone traffic laws, with a specific emphasis on the effects of UTO and other speed management measures on driver compliance with reduced work zone speed limits. The primary objective of this work is to assess the effectiveness of these interventions on maintaining safe travel speeds and to help guide the VAOT in the provision of proper resource allocation for improving work zone safety. Five types of work zone speed management scenarios have been examined in this project; they are:

1. The use of UTO at selected periods when the work zones are active;
2. Targeted police enforcement of speeds at selected periods when the work zones are active;
3. The use of flaggers to direct traffic and manage lane closures;
4. The deployment of Radar Speed Feedback Signs (RSFS) that post the work zone speed limit, as well as detect and display the travel speeds of approaching vehicles; and
5. The combination of both UTO and RSFS at selected periods when the work zones are active.

In all applicable scenarios, the travel speeds were measured for at least one week before, during, and after their implementation to examine the effects of the interventions. The collection of this large amount of data allowed for statistical testing of mean speeds for the different periods, as well as comparisons between proportions of vehicles that were over the speed limit or speeding excessively during these times.



## 2. Literature Review

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### 2.1 Crash Rates

Crash rates are higher overall in work zones when compared to non-work zones. Garber and Zhao (2002) found the activity area to be the most prevalent crash location in a work zone. The most common severity type was shown to be property damage only, next being injury, then fatal crashes making up the smallest portion. The most common type of collision was rear end, particularly in the advance warning area. Sideswipe crashes increase in the taper area. Both fixed object off-road and angle crashes increase in the work area itself.

### 2.2 Interventions

Ullman et al. (2013a) discussed two schools of thought regarding passive (i.e., police presence) versus active enforcement at work zones. Those favoring active enforcement point to possible reduced impact over time if the police is merely present and no citations are given, claiming that drivers eventually believe they will not be cited, thus lessening their compliance with work zone traffic laws. Conversely, champions for passive police presence claim that pursuit and citation of violators removes presence of law enforcement officers from work zones, thus reducing their effect. In their study, Ullman et al. (2013a) compared passive and active enforcement through driver surveys and field data collection. They showed that passive police presence does not necessarily lower drivers' reactions compared with active enforcement. Although drivers expressed they often realize law enforcement officers are not issuing citations, they do understand law enforcement presence indicates a road hazard and the importance to slow down. Ullman et al. (2013a) still recommended employing active enforcement from time to time to avoid drivers getting too sure they will not receive citations. They emphasized that work zone enforcement is optimal when the public benefits equal or exceed the costs of enforcement. These benefits can include both reduced crash costs and reduced motorist delay costs from the traffic-calming effect of the presence of law enforcement officers.

In another study, Ullman et al. (2013b) also compared different models for administrating and funding the acquisition of law enforcement services in work zones. These include project-by-project or program-wide funding agreements between highway and law enforcement agencies. Using a project-by-project method can allow for faster allocation of resources and reduce administrative costs, but can also be more challenging to adapt to changes in project scope and schedule. Program-wide funding can increase adaptability when a project's needs grow beyond the original scope, allow costs to be recaptured by the highway agency, and improve uniformity of enforcement services across a region or state. Program-wide funding can also require considerable costs to manage, though, and these costs can reduce the funds available for actual hours for UTO.

Bloch (1998) compared the use of photo-radar speed enforcement and speed display boards, and found that they have equal effectiveness during deployment. He found that supplemental police enforcement significantly increases the downstream effectiveness of speed display boards. The impact of photo-radar, speed display boards, and speed display boards with enforcement are all greater on excessive speeds than mean speeds, with reductions of 30.2 percent, 34.9 percent, and 31.8 percent, respectively. Comparing the cost-effectiveness of these three speed control measures, Bloch (1998) found the unenforced speed display board to have the greatest cost-effectiveness, the enforced speed display board next, with photo-radar being least cost-effective. These rankings of cost-effectiveness were consistent whether looking at cost per deployment, cost per kilometer per hour of speed reduction, or cost per driver (or vehicle) exposed. The conclusion was that speed display boards give the best outcomes among the three methods.

After an extensive review of available methods, Brewer et al. (2005) focused on three low cost, readily available treatments: orange-border speed limit signs, Radar Speed Feedback Signs (RSFS), and Portable Changeable Message Signs (PCMS). RSFS were shown to be successful at lowering drivers' speeds, increasing work zone speed limit conformity, and had the highest effect early in the work zone among the three treatments. They pointed to a psychological effect that RSFS have on drivers, making drivers think it's possible that law enforcement is in the vicinity. They said that occasional law enforcement presence helps to support this impression. The study also demonstrated that long-term results of RSFS last better than other methods. Appropriate work zone speed limit designations were emphasized as important for optimal compliance.

Bowie (2003) compared the effectiveness of three conditions: standard Manual on Uniform Traffic Control Devices (MUTCD) signs and barriers alone (no-treatment case), treatment using Speed Monitoring Displays (SMD) (i.e., RSFS), and treatment using police presence (UTO). She found the effect of SMD to be statistically significant at the 95 percent confidence level, although less than with police presence. Effectiveness of SMD alone was reduced when used over several weeks, compared with a lasting effectiveness when using police presence over several weeks. However, while the impact of police presence is localized, the impact of SMD continues downstream.

Pesti and McCoy (2001) studied the long-term effectiveness of SMDs. They found SMDs to be successful in reducing driver speeds and improving speed uniformity over five weeks. A halo effect was also observed for these measures, although it might not be as relevant to areas with larger proportions of commuter drivers. The best results were found on passenger cars compared with other vehicle types.

Mattox et al. (2008) developed and evaluated a speed-activated sign to reduce speeds in work zones. The sign consists of a radar assembly, a flashing beacon light that is activated when a speed threshold is met, a typical 4-foot by 4-foot orange diamond shaped construction sign, with the message, 'YOU ARE SPEEDING IF FLASHING', and two 1-foot by 1-foot orange flags for better visibility. The cost of production (~ \$1,500) was much less than RSFS and other

technologies. The sign met goals of the state transportation agency for a low-cost, convenient solution for lowering work zone speeds. The research showed reductions in mean speed, 85th percentile speeds, and excessive speeds. They recommend the use of the speed-activated signs for short-term work zones.

Wang et al. (2003) evaluated the effectiveness of fluorescent orange sheeting, innovative message signs, and changeable message signs with radar for highway work zone speed control. They tested both the immediate and novelty effect of treatments. The study found fluorescent orange sheeting reduced speed 1-3 mph, with an increase in speed variance and variability in novelty effect from site to site. Innovative message signs (e.g., "Slow Down, My Dad Works Here") showed less speed reduction immediately, but greater novelty effects. The changeable message signs with radar were shown to reduce speeds 7-8 mph without a decline in effect over time.

### 3. Research Methodologies

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#### 3.1 Speed Data Collection

The iCone system<sup>1</sup> was used in this project to collect vehicle travel speed data. The system includes the iCone devices, which look like typical orange and white striped traffic barrels with radar speed detection equipment and battery power housed inside (see Figure 1), and a central website to which the data is transmitted via satellite every two minutes and stored. The data transmitted include the latitude and longitude of the device, its battery charge status, the date and time of the readings, and a frequency count of vehicle speed readings in 5-miles per hour bins (e.g., 0 to 5 mph, 5 to 10 mph, etc.). The iCone devices do not necessarily register every vehicle separately; platooned vehicles (i.e., a line of vehicles traveling close to each other at approximately the same speed) may be registered as a single reading. Further, data collection is interrupted for approximately two seconds out of every two minutes for satellite transmission of the data to the central database. Travel speed data collected by the iCone devices is intended to be a representative sampling of the passing traffic.

For purposes of this study, the iCone devices were positioned on roadsides near highway construction projects. At various projects, depending on the road and project configuration as well as the safety intervention being evaluated, the iCone devices were positioned upstream, within, and downstream from the work zone.



Figure 1 The iCone devices

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<sup>1</sup> <http://iconeproducts.com/>

### **3.2 Data Collection Locations**

Ten highway construction project locations in the state of Vermont were considered for this study. Data was collected and analyzed for three of these locations during the construction season in 2012 and another three locations were included in 2013. Figure 2 shows the locations of the sites that were considered but excluded, as well as the locations where data was collected and analyzed.

Each of the following subsections provides the construction project description of a location where data was collected. They include the type of roadway, the type of construction work, the placements of the iCone devices, as well as any other relevant parameters.

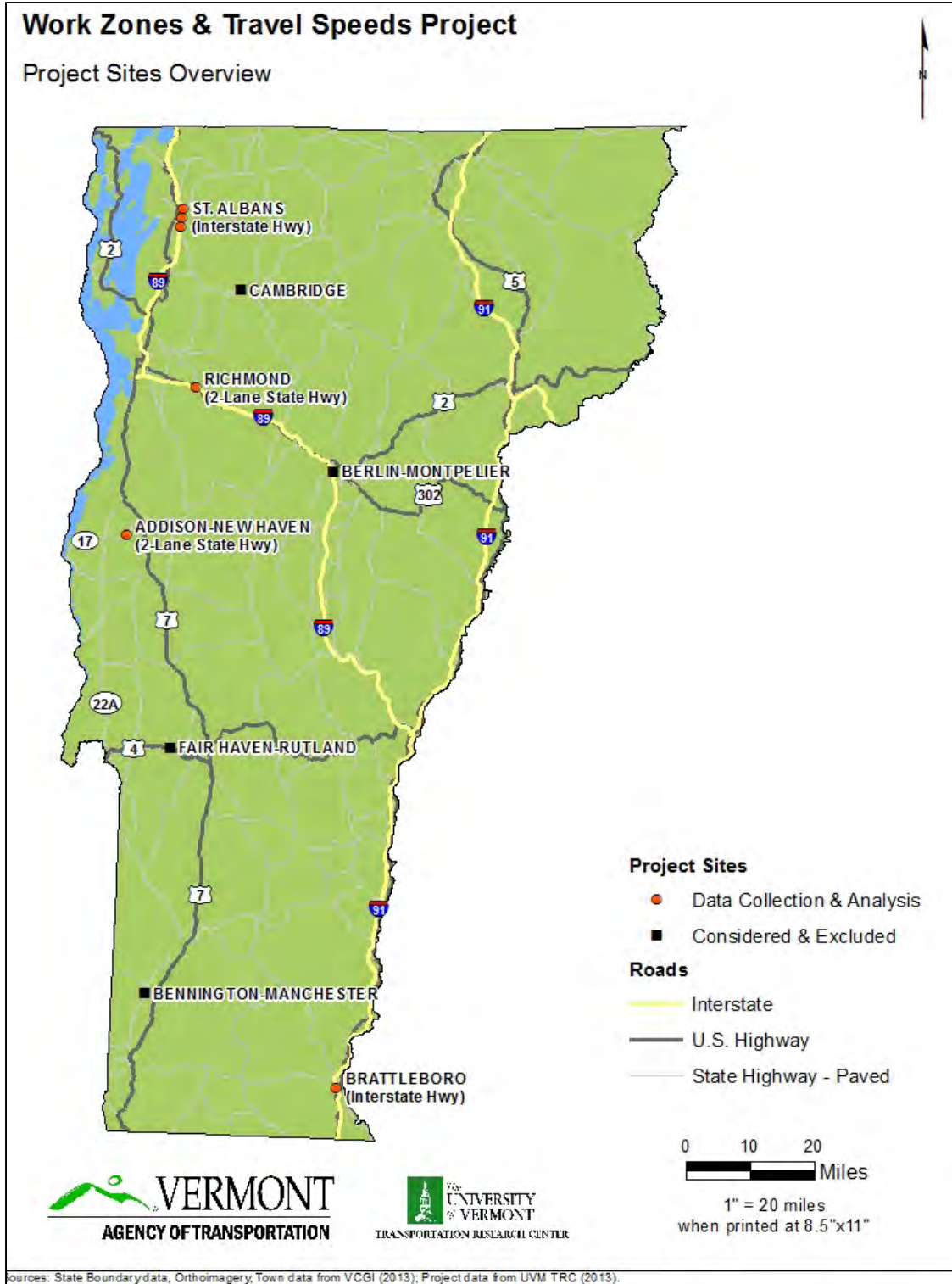


Figure 2 Data Collection Locations

### 3.2.1 Richmond (US Route 2, Eastbound Traffic Only) Data Collection, Validation, and Data Analysis

The Richmond construction project involved the expansion of an existing bridge over the Winooski River on a two-lane, two-way section of US Route 2, less than 1,000 feet west of Vermont Route 117 and the interchange with Interstate 89. Traffic was diverted to a temporary bridge adjacent to the existing bridge for the duration of the project. Due to the proximity of the traffic signal at the intersection with Vermont Route 117 east of the bridge, only the eastbound traffic was considered for this study because the westbound traffic was controlled by the signal and, therefore, not free flowing.

For the duration of this bridge expansion project, the speed limit for eastbound US Route 2 was reduced to 40 mph approximately 0.5 mile west of the work zone. The first iCone was deployed within this section (see Figure 3). The eastbound speed limit was dropped to 25 mph approximately 1,000 feet west of the temporary bridge. There was a small temporary parking area adjacent to the west end of the temporary bridge where the Richmond Police would sporadically park to monitor speeds and ticket violators who were traveling westbound over the temporary bridge. This active police enforcement (primarily for the westbound traffic) was considered the intervention at this location for the eastbound traffic. The second iCone was deployed just east of the temporary bridge, downstream from where the eastbound motorists would have passed the police enforcement activities (see Figure 4).



Figure 3 Richmond iCone 1, in the Eastbound 40-mph Section



The research objective at this Richmond project was to evaluate differences in speed of the traffic traveling eastward through the project site. Drivers would not have seen the police when they passed the first iCone in the 40 mph zone, but they would have driven passed the police when they got to the second iCone in the 25 mph zone. Although the eastbound drivers were not the primary targets of the enforcement action, the presence of the police and the enforcement activities were expected to have an impact on eastbound travel speeds.



**Figure 4** Richmond iCone 2, in the Eastbound 25-mph Section

Since US Route 2 is a two-lane, two-way road and radar can detect speeds of vehicles traveling in both directions, the iCones had to be carefully positioned to capture vehicles on one side of the road only. To accomplish this, the radar in the iCone devices had to be pointed approximately 5 to 10 degrees away from the road, so that the 45-degree cone within which they take measurements only extended to the centerline of the roadway.

Two forms of validation were used to confirm that the iCones were correctly positioned to only measure the travel speeds of eastbound traffic. First, a researcher conducted 15-minute traffic



counts at each of the two iCones on 16 August 2012; each manual count was compared to the corresponding data collected by an iCone. This was done in three iterations for both iCones, with adjustments to their positions made between each count to calibrate the direction in which the radar in each device was pointed.

After the iCones were positioned so as to capture the eastbound traffic with little or no westbound traffic, a video camera was installed to record the traffic passing by the second iCone, the one closest to the temporary bridge in the 25-mph section (see Figure 5). The camera was in place from 31 August 2012 through 27 September 2012.



**Figure 5 Video Camera Installation near Richmond iCone 2, in the Eastbound 25-mph Section**

The video recordings were reviewed to count the number of vehicles traveling in the eastbound direction in 15-minute intervals during daylight hours. These manual counts were compared to the iCone counts for the same time periods. In making the count comparisons, the 15-minute daylight intervals were divided into quartiles based on traffic volume, to evaluate whether there was a difference in the accuracy of the iCone counts during low, medium, and high traffic periods. The data was also sorted based on battery changes for the iCones in order to evaluate whether the accuracy was affected by the iCones being moved out of position and then replaced while the batteries were being replaced. Finally, the video recordings were also used to determine the time periods when the Richmond Police were present to conduct speed enforcement.

Police presence was sporadic and often brief, ranging from 3 to 20 minutes in duration at a stretch, with one or two visits to the site per day on weekdays only. Traffic speed before, during, and after the police presence was compared using the data from both iCones. Since the police presence averaged 11 minutes each day, the average speed during the time the police were on site was compared to the average speed during the 10 minutes before they arrived each day and the 10 minutes after they left.

The most disaggregated data provided by the iCones is in two-minute intervals and distributed into 5-mph bins. In order to estimate the mean speed and standard deviation over the time periods to be compared, we expanded the binned data into individual speed readings using central values for each bin. For example, for the 45-50 mph bin we used 47.5 mph. If there were 12 readings in the 45-50 mph bin we created 12 readings of 47.5 miles per hour. We created a data table in a spreadsheet with the correct number of entries at each speed, and then used this table to calculate the mean speed before, during, and after enforcement. We used t-tests to evaluate whether observed differences in mean speed were statistically significant. We also calculated and compared the number and percentage of vehicles traveling in excess of the work zone speed limit before, during, and after enforcement.

### **3.2.2 Brattleboro (Interstate 91) Data Collection and Analysis**

The Brattleboro project involved bridge construction work on Interstate 91, a four-lane divided freeway (two lanes in each direction), between exits 1 and 2. For the duration of the study, all southbound interstate traffic was channeled over to the northbound side to allow work on the bridge structure that carried the southbound lanes over the Whetstone Brook, a branch of the nearby Connecticut River. This temporary cross-over traffic configuration reduced one lane in each direction, leaving only one lane for southbound traffic and likewise for northbound traffic. The speed limit in the work zone was reduced to 50 mph (from 65 mph) for both directions and was set at that speed for the entire distance of the crossover.

There were six iCones deployed for this project. Three were positioned in each direction to capture the speeds of traffic in three different sections: approximately one mile upstream from the start of the work zone, within the 50 mph section where two lanes have merged into one,

and downstream from the work zone where the traffic pattern have returned to normal. All six iCones were in place from 31 August 2012 to 27 September 2012.

Although the iCones collected data 24 hours per day, only data from work hours when construction was active (typically 7 am to 7 pm on weekdays) was used for analysis. The data from the work periods was divided into three categories:

1. Times when the state police conducted speed enforcement for northbound traffic only;
2. Times when the state police conducted speed enforcement for both directions; and
3. Times when there was no speed enforcement activities.

Using these three categories, the number of vehicles in each of the 5-mph bins was summed for each of the six iCones for analysis.

The data was used to calculate the number and percentage of people traveling in excess of the applicable speed limit during northbound only enforcement periods, two-way enforcement periods, and no-enforcement periods for all six iCones. The observed differences in percentages were evaluated using a z-test to determine whether they are statistically significant.

In addition, the data was “unbinned” using the same method as for the Richmond iCones; the resulting tables were used to calculate the mean speed at each iCone during northbound enforcement, two-way enforcement, and no-enforcement periods. The t-test was used to determine whether observed differences in mean speed for these three categories were statistically significant.

### **3.2.3 Addison-New Haven (Vermont Route 17) Data Collection and Analysis**

The Addison-New Haven project included the improvement and repaving of a 7.3-mile stretch of Vermont Route 17, a two-lane, two-way state highway that runs east-west between Vermont Route 7 to the east and US Route 22A to the west. During the road reconstruction project, the speed limit was reduced to 45 mph for the entire seven-plus-mile stretch of road. When there were people or equipment working on the project, passage was limited to a single lane of travel. Flaggers were posted at each end of the work zone, stopping traffic to allow only one direction through the work zone at a given time. The length of single direction traffic depended on the expanse of the work being performed, and could range from just a few yards to a half-mile or more.

Two iCones were placed at this project on 1 October 2012. Both devices were placed on the north side of the road near the middle of the work zone; one was situated 3.3 miles from the eastern boundary of the project (iCone1) and the other 3.7 miles from that same reference (iCone2). They were both positioned to capture traffic traveling in either direction (i.e., the count and speed measurements are of both eastbound and westbound traffic). The iCones were in place for approximately four weeks until 1 November 2012. One of the iCones

disappeared from the site in the previous night (Halloween night); the other device was removed by the vendor a few days later.

A base coat of pavement had been applied to the entire length of the project before the iCones were deployed. The primary work activities during the four-week period when the iCones were collecting data included ditching and paving. Daily work locations changed throughout the entire length of the project and were recorded by the project Resident Engineer.

The distance from where active work was performed to each of the iCones was calculated for each day that data was collected. On most days, there were multiple crews working at multiple locations. Moreover, work on a given day often covered a span of road ranging from 30 feet to 700 feet or more. In all such instances, the closest work location to the iCones for the day was used.

The average speed of traffic at each of the two iCones was calculated for the heart of the work day, between 7:30 am and 4 pm. This calculation was based on the average speed registered by the iCone for each two-minute interval during that time period multiplied by the number of readings during that two-minute interval. Note that these are not the averages of the actual speed readings, which were not retained by the iCones, but rather the average of the binned data values, using central values for each bin (as was described for the Richmond project). The average speed for the work day was plotted against the distance from the nearest work site for that day and a spreadsheet was used to fit both a linear function line and a log function line to the data.

### **3.2.4 Saint Albans (Interstate 89, 3 locations) Data Collection and Analysis**

During the construction season of 2013, the Interstate 89 Richmond to Highgate Bridge Painting project was selected for data collection. Six bridges that cross over Interstate 89 (two in Milton, one in Georgia, and three in Saint Albans) were identified as locations on the freeway where there would be a lane drop and work zone speed limit reduction (from 65 mph to 50 mph) in both directions. After a review of each of the potential sites, it was decided that the three bridge locations in Saint Albans would be used for data collection. These are Bridge 89, Bridge 90, and Bridge 91, from south to north, and they were scheduled to be painted one at a time in that sequence. Figure 6 shows the location of these bridges.

From 7 May to 14 May 2013, speed data was collected at each of the three bridge locations before construction began. One iCone was deployed for each direction of travel (northbound and southbound) at each of the three bridge locations.

The project traffic control plan specified that UTO would be used only when a lane drop taper was being installed and removed. This provided us with an opportunity to study the effects of adding UTO presence (or other speed management interventions) at controlled times during the project in order to compare speed and other traffic behavior with and without UTO.

After the work zone traffic control package has been installed in both directions at a bridge site where work was active, six iCones were deployed, three for northbound and three for southbound (see Figure 6 for the deployment locations). In each direction, the first iCone was deployed in advance of the work zone, the second was deployed in the work zone where there is a speed limit reduction and traffic has been funneled from two lanes into one, and the last device was deployed beyond the work zone after the speed limit has been resumed and all traffic lanes are open.

During the construction period at each bridge, the first week of data collection was to establish baseline speeds with the work zone, lane closure, and speed limit reduction in place but no speed management interventions. In the second week of data collection, an intervention was deployed. Finally, post-intervention speed data was collected in the third after the intervention was removed. The interventions tested at the three bridge locations were:

- UTO at Bridge 89;
- RSFS that post the work zone speed limit, as well as detect and display the travel speeds of approaching vehicles at Bridge 90 (see Figure 7); and
- Both UTO and RSFS at Bridge 91.



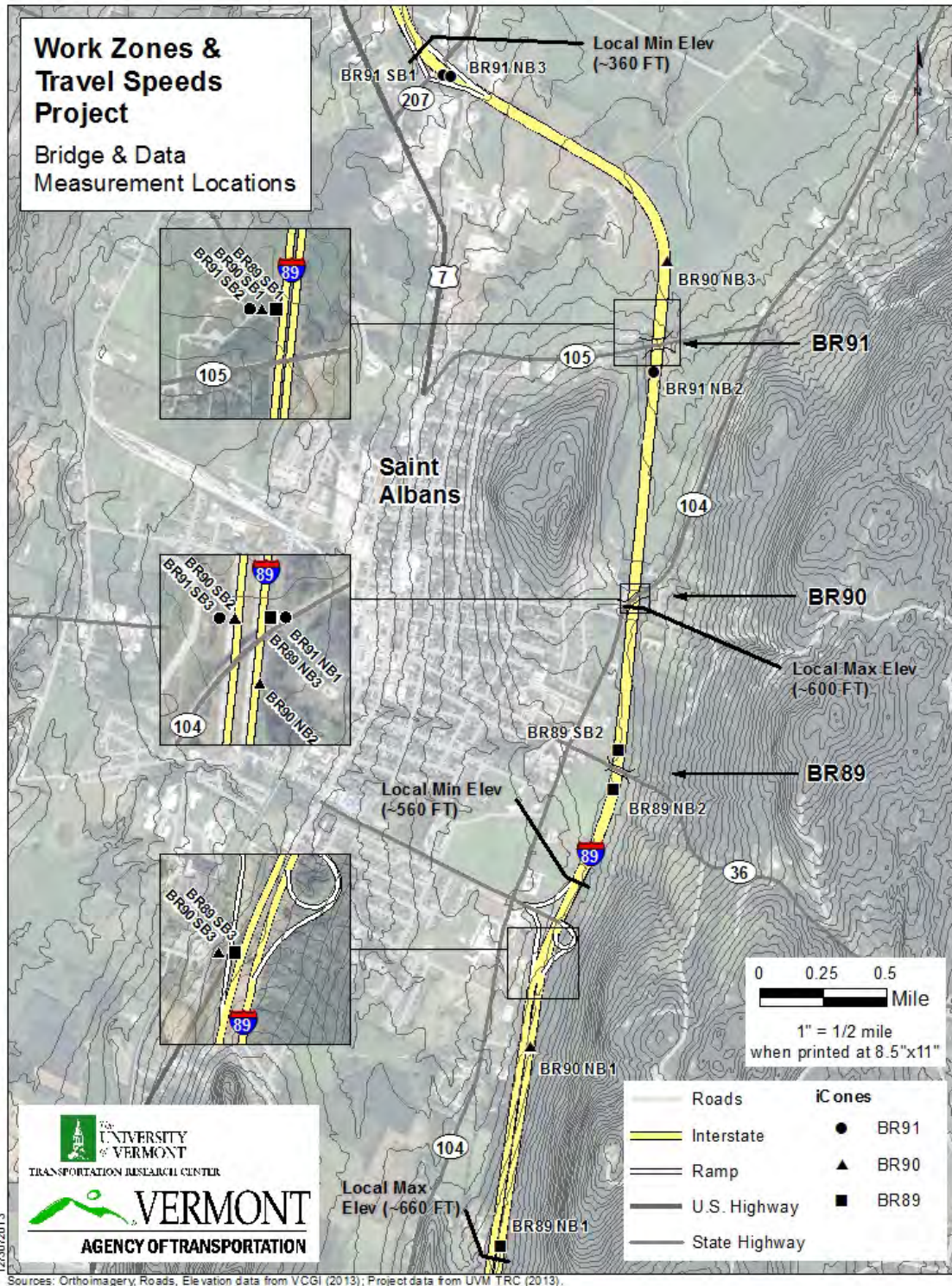


Figure 6 Saint Albans Data Collection Locations



**Figure 7 Saint Albans Bridge 90, Northbound RSFS**

The speed data collected at each bridge location was used to calculate the number and percentage of people traveling in excess of the applicable speed limit for all six iCones. The observed differences in percentages were evaluated using a z-test to determine whether they are statistically significant.

Same with all other sites, the data from these three bridge location was “unbinned” using the method described for the Richmond iCones. The resulting tables were used to calculate the mean speed at each iCone location during the pre-intervention, intervention, and post-intervention periods. The t-test was used to determine whether observed differences in mean speed for these periods were statistically significant.

## 4. Results

### 4.1 Richmond (US Route 2, Eastbound Traffic Only) – Police Enforcement

Table 1 below shows the mean speeds for eastbound traffic before, during, and after police enforcement activities. Eastbound traffic passing the first iCone (before entering the work zone area and where the speed limit has been reduced to 40 mph) was moving at a mean speed of 43.2 mph during the 10 minutes immediately preceding the times when a police officer was conducting speed enforcement for westbound traffic in the work zone. During the times when there was active police enforcement in the work zone (for westbound traffic), the eastbound traffic mean speed dropped to 42.1 mph. Although small, a t-test confirms that this difference is statistically significant. During the 10 minutes after enforcement was concluded for the day, the mean speed increased to 43.1 mph, and again the difference in mean speed is statistically significant. Note that at the location of the first iCone, drivers of the eastbound vehicles should not be able to see where the police vehicles are parked and monitoring the westbound traffic; it is, therefore, not completely clear why the mean speeds during the police enforcement periods were statistically lower than before and after. At the second iCone location where drivers would have seen and passed the police enforcement activities, the mean speed dropped from 27.5 mph during the 10 minutes before the police arrived to 25.5 mph during the period when the police was present, and increased to 27.4 after they departed. The differences in mean speeds between these periods are much greater (in absolute and percent terms) when compared to those at the first iCone location and are also statistically significant.

**Table 1 Richmond (US Route 2, Eastbound Traffic Only) Mean Speeds Before, During, and After Police Enforcement**

Location	Speed Limit (mph)	Before Police Enforcement: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During Police Enforcement: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After Police Enforcement: Mean Speed (mph)
iCone 1 (upstream from work zone)	40	43.2	Yes ( $p < 0.001$ )	42.1	Yes ( $p < 0.001$ )	43.1
iCone 2 (in work zone)	25	27.5	Yes ( $p < 0.001$ )	25.5	Yes ( $p < 0.001$ )	27.4

Table 2 below summarizes the percentage of eastbound traffic that exceeded the speed limit before, during, and after the police enforcement activities for the westbound vehicles. At the first iCone, the proportion of vehicles traveling above the speed limit (40 mph) decreased when the police officer was present. In the period immediately before there were active westbound



enforcement activities, 75% of the eastbound traffic exceeded the speed limit. During the speed enforcement period, that proportion dropped to 68%. After the police had departed, the proportion rebounded to 71%. Although those percentages may sound surprisingly high, most traffic only exceeded the speed limit by less than 5 miles per hour. The percent traveling in excess of 45 mph is only 8% before the police arrived, 7% while they were present, and 10% after they departed. As noted above, it is unclear why these proportions were lower during the police enforcement periods since the drivers of these vehicles would likely not have seen the enforcement activities from this point.

**Table 2 Richmond (US Route 2, Eastbound Traffic Only) Percentage of Traffic Exceeding Speed Limit**

	<u>Before Police Enforcement:</u> Percentage of Traffic (%)	<u>Before/During Percentages:</u> Statistically Different?	<u>During Police Enforcement:</u> Percentage of Traffic (%)	<u>During/After Percentages:</u> Statistically Different?	<u>After Police Enforcement:</u> Percentage of Traffic (%)
<b>iCone 1 (upstream from work zone)</b>					
Exceeding speed limit	75	Yes ( $p < 0.001$ )	68	Yes ( $p < 0.001$ )	71
Exceeding by >5 mph	8	Yes ( $p < 0.001$ )	7	Yes ( $p < 0.001$ )	10
<b>iCone 2 (in work zone)</b>					
Exceeding speed limit	75	Yes ( $p < 0.001$ )	59	Yes ( $p < 0.001$ )	64
Exceeding by > 5 mph	25	Yes ( $p < 0.001$ )	13	Yes ( $p < 0.001$ )	17

At iCones 2, the percent of vehicles traveling above the speed limit (25 mph) decreased from 75% before the police arrived to 59% while they were present, and then went back up to 64% during the 10 minutes after they departed. The percent of vehicles traveling more than 5 mph over the speed limit is 25% before the police arrived, 13% while they were present, and then went back up to 17% after they departed. It is clear from this location that the police enforcement activities had a direct impact on the speeds of the eastbound traffic, even though the targets for the police were the westbound vehicles.

#### 4.2 Brattleboro (Interstate 91) – Police Enforcement

Table 3 below tabulates the mean speeds of both northbound and southbound traffic on Interstate 91 for periods with and without police enforcement activities during daylight hours. When there was no enforcement present, the mean speeds passing the three iCones measuring northbound traffic was 61.4 mph, 53.3 mph, and 58.1 mph for the iCone upstream from the work zone (NB1), immediately following the merge in the work zone (NB2), and downstream from the workzone (NB3), respectively. When enforcement was present, the mean speeds decreased to 61.1 mph, 52.6 mph, and 56.3 mph, respectively. For southbound traffic when there was no enforcement present, the mean speed was 61.9 mph upstream from the workzone (SB1), 51.6 mph in the work zone immediately following the merge (SB2), and 54.0 mph downstream from the workzone (SB3). When police were on the scene performing speed enforcement activities, the mean speeds were 62.1 mph, 50.8 mph, and 53.2 mph, respectively.

With the exception of iCone SB1, all of the mean speeds for both northbound and southbound traffic were lower during the daylight periods when there were police enforcement activities than when there was not.

**Table 3 Brattleboro (Interstate 91) Mean Speeds Without and With Police Enforcement**

Location	Speed Limit (mph)	Without Police Enforcement: Mean Speed (mph)	With Police Enforcement: Mean Speed (mph)	Without/With Mean Speeds: Statistically Different?
<b>Northbound</b>				
iCone NB1 (upstream from work zone)	65	61.4	61.1	Yes ( $p < 0.001$ )
iCone NB2 (in work zone)	50	53.3	52.6	Yes ( $p < 0.001$ )
iCone NB3 (downstream from work zone)	65	58.1	56.3	Yes ( $p < 0.001$ )
<b>Southbound</b>				
iCone SB1 (upstream from work zone)	65	61.9	62.1	Yes ( $p < 0.001$ )
iCone SB2 (in work zone)	50	51.6	50.8	Yes ( $p < 0.001$ )
iCone SB3 (downstream from work zone)	65	54.0	53.2	Yes ( $p < 0.001$ )

The differences between the mean speeds at a given iCone when police were present or not are statistically significant at the  $p < 0.001$  level for all locations. The first southbound iCone (SB1), however, had a difference in mean speeds that is in the opposite direction; the mean speed for the no police enforcement periods was greater than that for the police enforcement periods. Note that southbound vehicles captured at this location would not have seen the work zone where the enforcement activities were focused, so it is unlikely that the police would be linked to this unexpected result.

Consistent with the findings from the Richmond location, the proportion of vehicles traveling above the speed limit also generally decreased when the police officer was present. Again, the only exception was for the first southbound iCone (SB1) where the proportions with and without police enforcement are statistically the same. In all other cases, the decreases are statistically significant. Table 4 below summarizes these results.

**Table 4 Brattleboro (Interstate 91) Percentage of Traffic Exceeding Speed Limit**

	<b>Without Police Enforcement: Percentage of Traffic (%)</b>	<b>Without/With Percentages: Statistically Different?</b>	<b>With Police Enforcement: Percentage of Traffic (%)</b>
<b>Northbound</b>			
iCone NB1 (upstream from work zone)			
Exceeding speed limit	29.8	Yes ( $p < 0.001$ )	27.5
Exceeding by >5 mph	8.3	Yes ( $p < 0.001$ )	7.0
iCone NB2 (in work zone)			
Exceeding speed limit	72.4	Yes ( $p < 0.001$ )	66.3
Exceeding by >5 mph	40.2	Yes ( $p < 0.001$ )	35.0
iCone NB3 (downstream from work zone)			
Exceeding speed limit	22.2	Yes ( $p < 0.001$ )	14.7
Exceeding by >5 mph	5.7	Yes ( $p < 0.001$ )	3.1
<b>Southbound</b>			
iCone SB1 (upstream from work zone)			
Exceeding speed limit	33.6	No ( $p = 0.12$ )	33.7
Exceeding by >5 mph	10.6	No ( $p = 0.08$ )	11.0
iCone SB2 (in work zone)			
Exceeding speed limit	56.6	Yes ( $p < 0.001$ )	51.1
Exceeding by >5 mph	28.1	Yes ( $p < 0.001$ )	24.4
iCone SB3 (downstream from work zone)			
Exceeding speed limit	6.7	Yes ( $p < 0.001$ )	4.9
Exceeding by >5 mph	1.0	Yes ( $p < 0.001$ )	0.72

### 4.3 Addison-New Haven (Vermont Route 17) – Flaggers and Single-lane Traffic

Figures 8 and 9 below show the daily mean speeds at the two iCone locations for this pavement work project. The graphs allow comparisons between the mean speeds of traffic in both directions on Sundays, when no work was being performed on this road, and the mean speeds on work days (Mondays through Saturdays). In general, the mean speeds were higher on Sundays, the non-work days, than in the other six days. This indicates that the presence of flaggers and active construction on the work days impacted the travel speeds of traffic on this road. It is possible, however, that the travelers on Sunday were of a different profiles from those on the other days but there are no obvious reasons why these Sunday travelers would on average be moving faster.

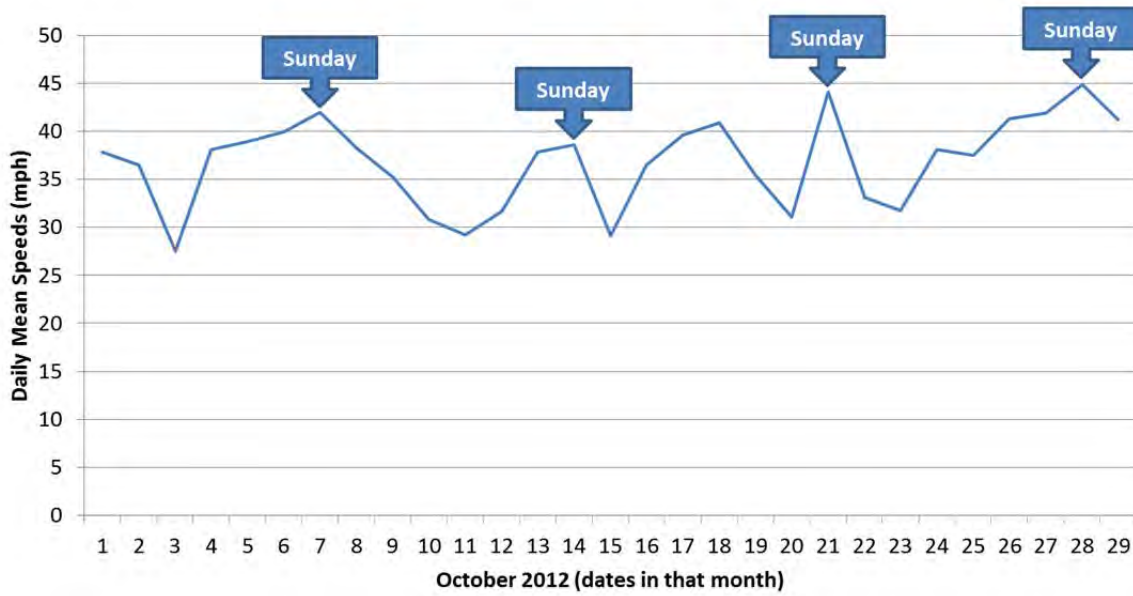


Figure 8 Addison-New Haven (Vermont Route 17) iCone 1 (East Location): Daily Mean Speeds

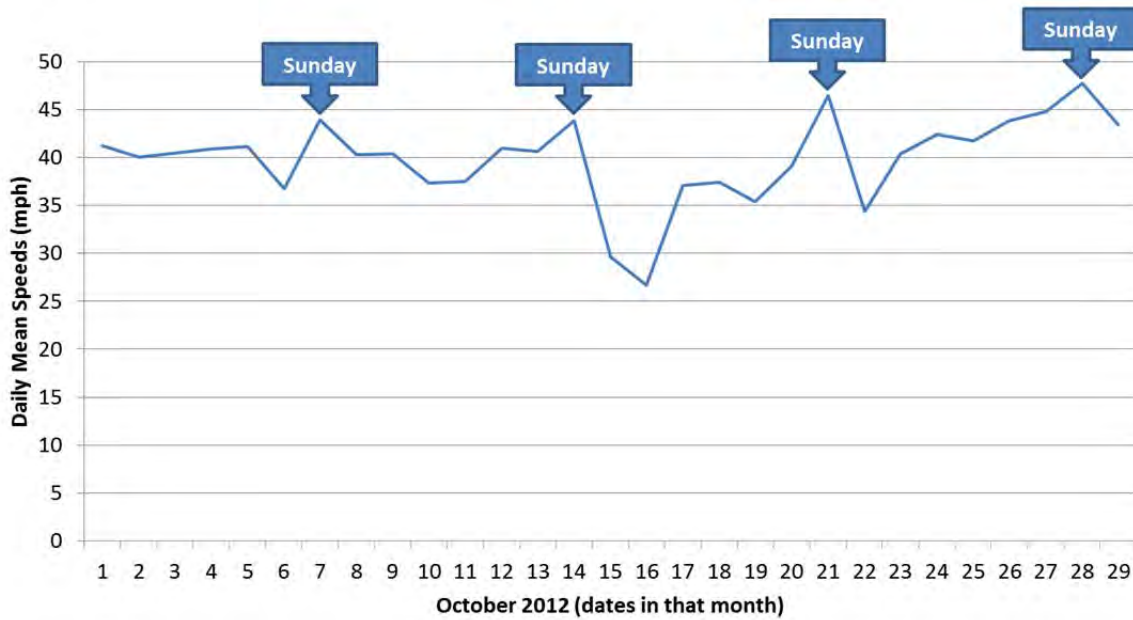
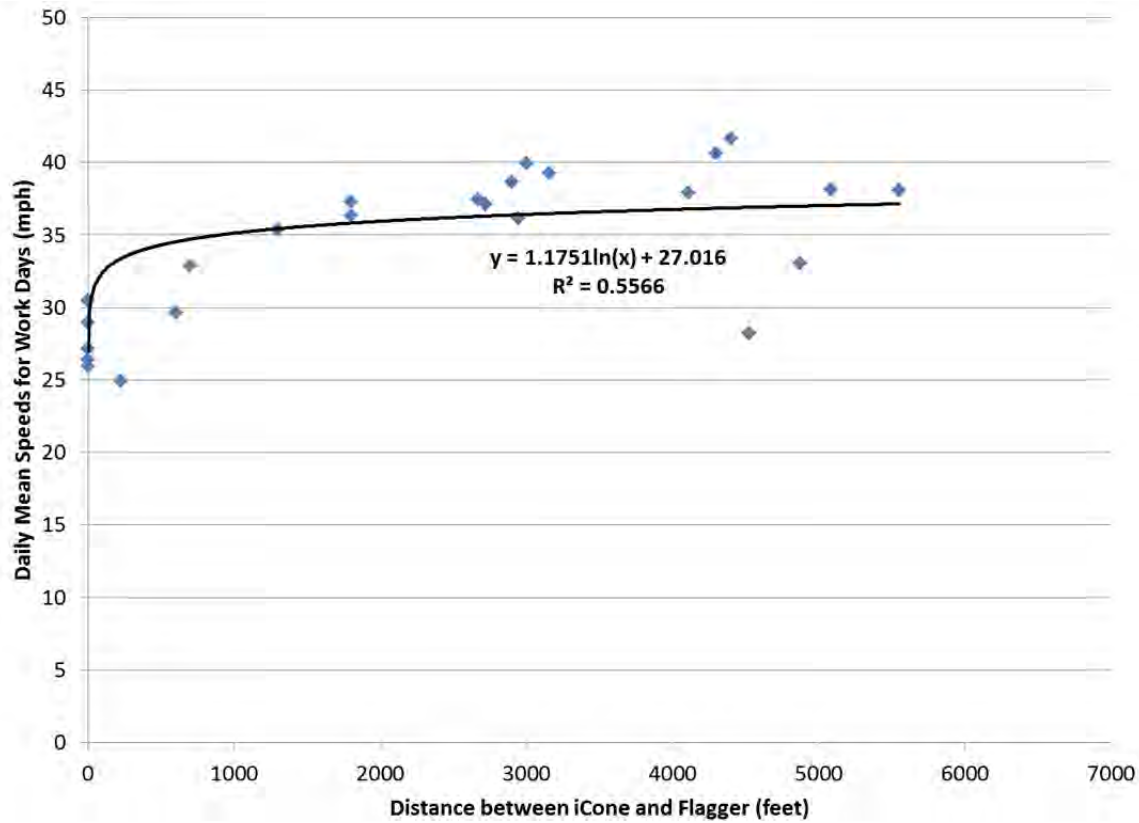


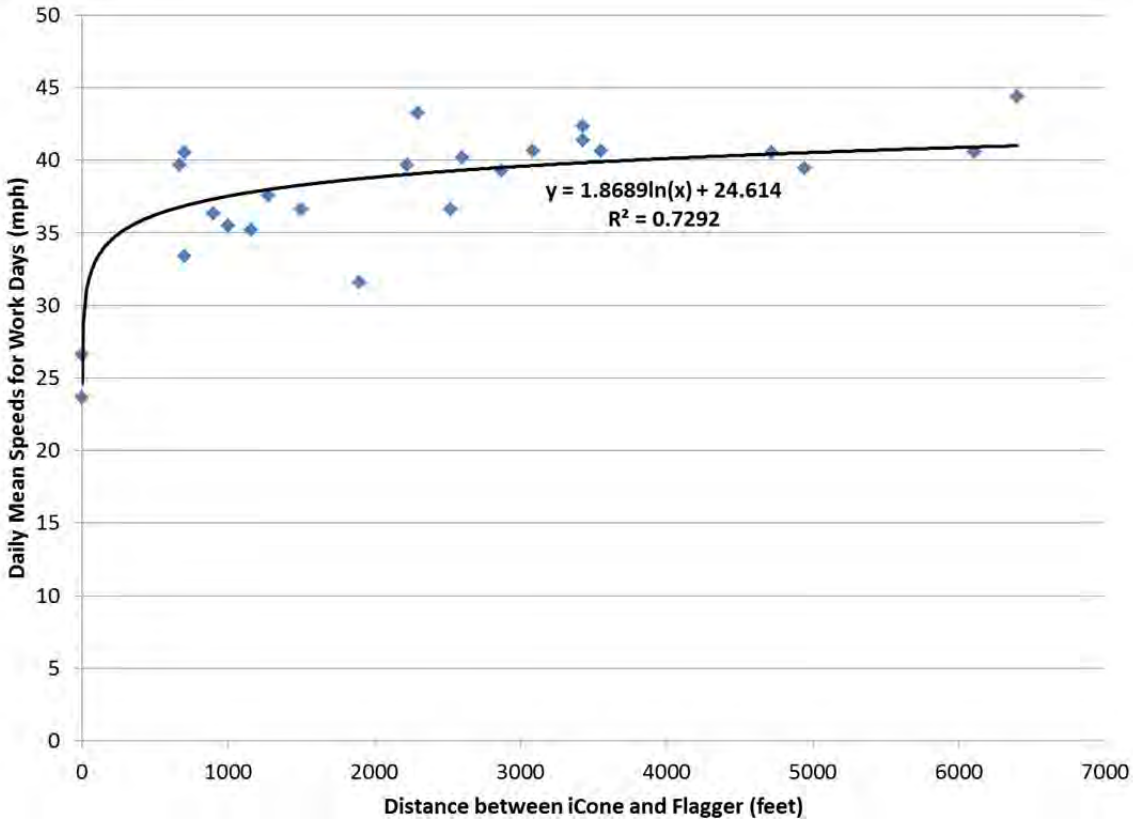
Figure 9 Addison-New Haven (Vermont Route 17) iCone 2 (West Location): Daily Mean Speeds

Since the daily work locations changed throughout the entire project, the distances from where active work was performed to the two iCones were calculated for each day that speed

measurements were taken. To examine the impact of the flaggers and lane closures on travel speeds along this road, the daily mean speeds were regressed against these distances (in logarithm scale). Figures 10 and 11 below show that there are strong log-linear relationships between the mean speeds and distance to the flaggers; the r-square values are 0.56 and 0.73 for iCone 1 (east location) and iCone 2 (west location), respectively. These graphs show that the impacts of the flaggers and lane closures on travel speeds dissipate in space and are generally negligible beyond about 3000 ft (or about half a mile) where the regression lines are almost flat.



**Figure 10 Addison-New Haven (Vermont Route 17) iCone1 (East Location): Daily Mean Speeds for Work Days vs. Distance between iCone and Flagger**



**Figure 11 Addison-New Haven (Vermont Route 17) iCone2 (West Location): Daily Mean Speeds for Work Days vs. Distance between iCone and Flagger**

#### 4.4 Saint Albans (Interstate 89, 3 locations) – UTO and RSFS

The following series of tables (5 through 16) summarizes the analysis results for speed measurements and interventions examined along Interstate 89 at Bridges 89, 90, and 91 in Saint Albans. Similar to the tables above for the Richmond (US Route 2) and Brattleboro (Interstate 91) locations, half of these tables show the mean speeds measured at various points upstream from, in, or downstream from a work zone for the periods before, during, or after an invention. The other half show the proportion of traffic that exceeded the speed limits at these points (upstream/in/downstream) for the different times (before/during/after intervention).

##### 4.4.1 Bridge 89 – UTO

Tables 5 and 6 below show the mean speeds for the same time periods each day in the weeks before, during, and after UTO were deployed for both northbound and southbound on Interstate 89 at Bridge 89. In both directions, the mean speeds in the work zone dropped by approximately 3 mph during the week when UTO were present, compared to the weeks before

and after when they are not. These differences are statistically significant to the  $p < 0.001$  level. In general, the mean speeds of vehicles downstream from the work zones also decreased during the week when the UTO were used, suggesting that there may be a small spatial halo effect. The exception is iCone NB3 where the mean speeds before and during the UTO deployment were statistically the same.

**Table 5 Saint Albans (Interstate 89 Northbound) at Bridge 89 Mean Speeds Before, During, and After UTO Presence**

Northbound Location	Speed Limit (mph)	Before UTO: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During UTO: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After UTO: Mean Speed (mph)
iCone NB1 (upstream from work zone)	65	68.4	Yes ( $p < 0.001$ )	67.7	Yes ( $p < 0.001$ )	68.4
iCone NB2 (in work zone)	50	50.3	Yes ( $p < 0.001$ )	46.9	Yes ( $p < 0.001$ )	50.2
iCone NB3 (downstream from work zone)	65	58.6	No ( $p = 0.298$ )	58.4	Yes ( $p < 0.001$ )	59.7

**Table 6 Saint Albans (Interstate 89 Southbound) at Bridge 89 Mean Speeds Before, During, and After UTO Presence**

Southbound Location	Speed Limit (mph)	Before UTO: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During UTO: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After UTO: Mean Speed (mph)
iCone SB1 (upstream from work zone)	65	60.1	No ( $p = 0.202$ )	60.2	Yes ( $p = 0.007$ )	60.5
iCone SB2 (in work zone)	50	53.0	Yes ( $p < 0.001$ )	49.1	Yes ( $p < 0.001$ )	52.8
iCone SB3 (downstream from work zone)	65	53.5	Yes ( $p < 0.001$ )	51.6	Yes ( $p < 0.001$ )	52.9

Tables 7 and 8 below tabulate the proportion of traffic in both northbound and southbound directions on Interstate 89 at this location that exceeded the speed limit. Reflecting the results in the two tables above, all of the proportions except those at iCone NB3 were significantly lower during the week when UTO were deployed. The drops were the most dramatic in the

work zone. There was a decrease of more than 30 points (from 49.4% to 18.4% and back up to 48.8%) for all northbound speeders at iCone NB2 and almost 20 points (from 23.8% to 4.5% and back up to 17.9%) for northbound speeders who exceeded the limit by more than 5 mph. The results were similarly dramatic for southbound speeders at iCone SB2.

**Table 7 Saint Albans (Interstate 89 Northbound) at Bridge 89 Percentage of Traffic Exceeding Speed Limit**

Northbound Location	Before UTO: Percentage of Traffic (%)	Before/During Percentages: Statistically Different?	During UTO: Percentage of Traffic (%)	During/After Percentages: Statistically Different?	After UTO: Percentage of Traffic (%)
<b>iCone NB1 (upstream from work zone)</b>					
Exceeding speed limit	72.8	Yes ( $p < 0.001$ )	69.1	Yes ( $p < 0.001$ )	73.5
Exceeding by >5 mph	34.9	Yes ( $p < 0.001$ )	31.2	Yes ( $p < 0.001$ )	35.4
<b>iCone NB2 (in work zone)</b>					
Exceeding speed limit	49.4	Yes ( $p < 0.001$ )	18.4	Yes ( $p < 0.001$ )	48.8
Exceed by > 5 mph	23.8	Yes ( $p < 0.001$ )	4.5	Yes ( $p < 0.001$ )	17.9
<b>iCone NB3 (downstream from work zone)</b>					
Exceeding speed limit	25.9	No ( $p = 0.596$ )	26.3	Yes ( $p < 0.001$ )	28.6
Exceeding by >5 mph	9.5	No ( $p = 0.381$ )	10.2	Yes ( $p < 0.001$ )	12.6

**Table 8 Saint Albans (Interstate 89 Southbound) at Bridge 89 Percentage of Traffic Exceeding Speed Limit**

Southbound Location	Before UTO: Percentage of Traffic (%)	Before/During Percentages: Statistically Different?	During UTO: Percentage of Traffic (%)	During/After Percentages: Statistically Different?	After UTO: Percentage of Traffic (%)
<b>iCone SB1 (upstream from work zone)</b>					
Exceeding speed limit	23.5	Yes ( $p < 0.001$ )	24.8	Yes ( $p < 0.001$ )	25.4
Exceeding by >5 mph	7.0	No ( $p = 0.835$ )	6.9	No ( $p = 0.496$ )	6.7
<b>iCone SB2 (in work zone)</b>					
Exceeding speed limit	68.3	Yes ( $p < 0.001$ )	39.7	Yes ( $p < 0.001$ )	66.9
Exceeding by > 5 mph	31.8	Yes ( $p < 0.001$ )	11.0	Yes ( $p < 0.001$ )	30.3
<b>iCone SB3 (downstream from work zone)</b>					
Exceeding speed limit	18.4	No ( $p = 0.596$ )	12.2	Yes ( $p < 0.001$ )	20.0
Exceeding by >5 mph	2.6	No ( $p = 0.381$ )	1.9	Yes ( $p < 0.001$ )	4.8

**4.4.2 Bridge 90 – RSFS**

Tables 8 and 9 below show the mean speeds for the weeks before, during, and after RSFS were deployed for both northbound and southbound Interstate 89 at Bridge 90. In the northbound direction, the mean speeds in the work zone dropped by approximately 4 mph during the week



when the RSFS was present compared to the week before, and almost 3 mph compared to the week after. The differences were smaller for the mean speeds in the southbound work zone but those speeds were lower. In both cases, the differences are statistically significant to the  $p < 0.001$  level. the mean speeds of vehicles downstream from the work zones were statistically different during the week when the RSFS were used, but not always in the expected direction. It is unclear whether there is any spatial halo effect.

**Table 9 Saint Albans (Interstate 89 Northbound) at Bridge 90 Mean Speeds Before, During, and After RSFS**

Northbound Location	Speed Limit (mph)	Before RSFS: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During RSFS: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After RSFS: Mean Speed (mph)
iCone NB1 (upstream from work zone)	65	63.4	Yes ( $p < 0.001$ )	64.4	Yes ( $p = 0.039$ )	64.6
iCone NB2 (in work zone)	50	54.4	Yes ( $p < 0.001$ )	49.3	Yes ( $p < 0.001$ )	52.5
iCone NB3 (downstream from work zone)	65	63.2	Yes ( $p = 0.046$ )	63.4	Yes ( $p < 0.001$ )	62.4

**Table 10 Saint Albans (Interstate 89 Southbound) at Bridge 90 Mean Speeds Before, During, and After RSFS**

Southbound Location	Speed Limit (mph)	Before RSFS: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During RSFS: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After RSFS: Mean Speed (mph)
iCone SB1 (upstream from work zone)	65	64.4	Yes ( $p < 0.001$ )	64.8	Yes ( $p < 0.001$ )	64.4
iCone SB2 (in work zone)	50	49.8	Yes ( $p < 0.001$ )	48.1	Yes ( $p < 0.001$ )	51.0
iCone SB3 (downstream from work zone)	65	52.7	Yes ( $p < 0.001$ )	52.5	Yes ( $p < 0.001$ )	53.9

Tables 11 and 12 below summarize the proportion of traffic in both northbound and southbound directions on Interstate 89 at Bridge 90 that exceeded the speed limit. All of the proportions, except for iCone NB3, were significantly lower during the week when the speed trailers were used. Similar to the UTO, the drops were the most dramatic in the work zone.

There was a decrease of almost 30 points (from 40.0% to 11.1% and back up to 31.4%) for all northbound speeders at iCone NB2 and more than 10 points (from 17.5% to 3.8% and back up to 13.0%) for northbound speeders who exceeded the limit by more than 5 mph. The results were less dramatic for southbound speeders at iCone SB2 because the proportions were low.

**Table 11 Saint Albans (Interstate 89 Northbound) at Bridge 90 Percentage of Traffic Exceeding Speed Limit**

Northbound Location	<u>Before</u> RSFS: Percentage of Traffic (%)	<u>Before/During</u> Percentages: Statistically Different?	<u>During</u> RSFS: Percentage of Traffic (%)	<u>During/After</u> Percentages: Statistically Different?	<u>After</u> RSFS: Percentage of Traffic (%)
<b>iCone NB1 (upstream from work zone)</b>					
Exceeding speed limit	39.7	Yes ( $p < 0.001$ )	47.5	Yes ( $p < 0.001$ )	48.8
Exceeding by >5 mph	12.9	Yes ( $p < 0.001$ )	18.3	Yes ( $p < 0.001$ )	16.9
<b>iCone NB2 (in work zone)</b>					
Exceeding speed limit	40.0	Yes ( $p < 0.001$ )	11.1	Yes ( $p < 0.001$ )	31.4
Exceed by > 5 mph	17.5	Yes ( $p < 0.001$ )	3.8	Yes ( $p < 0.001$ )	13.0
<b>iCone NB3 (downstream from work zone)</b>					
Exceeding speed limit	35.1	Yes ( $p < 0.001$ )	37.4	Yes ( $p < 0.001$ )	28.3
Exceeding by >5 mph	6.4	Yes ( $p < 0.001$ )	6.9	Yes ( $p < 0.001$ )	5.1

**Table 12 Saint Albans (Interstate 89 Southbound) at Bridge 90 Percentage of Traffic Exceeding Speed Limit**

Southbound Location	<u>Before</u> RSFS: Percentage of Traffic (%)	<u>Before/During</u> Percentages: Statistically Different?	<u>During</u> RSFS: Percentage of Traffic (%)	<u>During/After</u> Percentages: Statistically Different?	<u>After</u> RSFS: Percentage of Traffic (%)
<b>iCone SB1 (upstream from work zone)</b>					
Exceeding speed limit	47.0	Yes ( $p < 0.001$ )	51.3	Yes ( $p < 0.001$ )	48.1
Exceeding by >5 mph	18.0	Yes ( $p < 0.001$ )	21.2	Yes ( $p < 0.001$ )	20.1
<b>iCone SB2 (in work zone)</b>					
Exceeding speed limit	18.0	Yes ( $p < 0.001$ )	5.1	Yes ( $p < 0.001$ )	20.7
Exceeding by > 5 mph	6.4	Yes ( $p < 0.001$ )	1.5	Yes ( $p < 0.001$ )	7.7
<b>iCone SB3 (downstream from work zone)</b>					
Exceeding speed limit	14.9	Yes ( $p < 0.001$ )	14.1	Yes ( $p < 0.001$ )	16.5
Exceeding by >5 mph	2.3	Yes ( $p < 0.001$ )	2.1	Yes ( $p < 0.001$ )	2.2

**4.4.3 Bridge 91 – UTO and RSFS**

Tables 13 and 14 below show the mean speeds for the same time periods each day in the weeks before, during, and after both UTO and RSFS were deployed for the northbound and southbound directions on Interstate 89 at Bridge 91. In the northbound direction, the mean

speeds in the work zone dropped by more than 6 mph during the week when these two interventions were present compared to the week before, and more than 4 mph compared to the week after. The differences were slightly smaller for the mean speeds in the southbound work zone but those speeds were lower. In both cases, the differences are statistically significant to the  $p < 0.001$  level. Similar to only having the RSFS deployed, the mean speeds of vehicles downstream from the work zones were statistically different during the week when both the UTO and RSFS were used but those differences were small and some were actually larger. It is unclear whether there is any spatial halo effect.

**Table 13 Saint Albans (Interstate 89 Northbound) at Bridge 91 Mean Speeds Before, During, and After UTO Presence and RSFS**

Northbound Location	Speed Limit (mph)	Before UTO & RSFS: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During UTO & RSFS: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After UTO & RSFS: Mean Speed (mph)
iCone NB1 (upstream from work zone)	65	55.2	Yes ( $p < 0.001$ )	56.9	Yes ( $p < 0.001$ )	57.8
iCone NB2 (in work zone)	50	54.1	Yes ( $p < 0.001$ )	47.6	Yes ( $p < 0.001$ )	52.1
iCone NB3 (downstream from work zone)	65	61.1	Yes ( $p < 0.001$ )	61.5	Yes ( $p < 0.001$ )	59.9

**Table 14 Saint Albans (Interstate 89 Southbound) at Bridge 91 Mean Speeds Before, During, and After UTO Presence and RSFS**

Southbound Location	Speed Limit (mph)	Before UTO & RSFS: Mean Speed (mph)	Before/During Mean Speeds Statistically Different?	During UTO & RSFS: Mean Speed (mph)	During/After Mean Speeds Statistically Different?	After UTO & RSFS: Mean Speed (mph)
iCone SB1 (upstream from work zone)	65	62.8	Yes ( $p < 0.001$ )	63.7	Yes ( $p < 0.001$ )	62.7
iCone SB2 (in work zone)	50	51.0	Yes ( $p < 0.001$ )	45.9	Yes ( $p < 0.001$ )	48.2
iCone SB3 (downstream from work zone)	65	64.7	Yes ( $p < 0.001$ )	64.6	Yes ( $p < 0.001$ )	64.6

Tables 15 and 16 below summarize the proportion of traffic in both northbound and southbound directions on Interstate 89 at Bridge 91 that exceeded the speed limit. All of the proportions, except for iCone NB3 and SB3, were significantly lower during the week when the RSFS were used. Similar to the previous two cases, the drops were the most dramatic in the work zone. There was a decrease of more than 35 points (from 41.4% to 4.0% and back up to 27.9%) for all northbound speeders at iCone NB2 and more than 6 points (from 6.7% to 0.4% and back up to 3.9%) for northbound speeders who exceeded the limit by more than 5 mph. The results were less dramatic for southbound speeders at iCone SB2 because the proportions were low. In both directions, the proportions of speeders were brought down close to 0%.

**Table 15 Saint Albans (Interstate 89 Northbound) at Bridge 91 Percentage of Traffic Exceeding Speed Limit**

Northbound Location	Before UTO & RSFS: Percentage of Traffic (%)	Before/During Percentages: Statistically Different?	During UTO & RSFS: Percentage of Traffic (%)	During/After Percentages: Statistically Different?	After UTO & RSFS: Percentage of Traffic (%)
<b>iCone NB1 (upstream from work zone)</b>					
Exceeding speed limit	6.6	Yes ( $p < 0.001$ )	8.9	Yes ( $p < 0.001$ )	14.0
Exceeding by >5 mph	1.2	Yes ( $p < 0.001$ )	1.5	Yes ( $p < 0.001$ )	2.9
<b>iCone NB2 (in work zone)</b>					
Exceeding speed limit	41.4	Yes ( $p < 0.001$ )	4.0	Yes ( $p < 0.001$ )	27.9
Exceed by > 5 mph	6.7	Yes ( $p < 0.001$ )	0.4	Yes ( $p < 0.001$ )	3.9
<b>iCone NB3 (downstream from work zone)</b>					
Exceeding speed limit	24.6	Yes ( $p < 0.001$ )	27.4	Yes ( $p < 0.001$ )	19.1
Exceeding by >5 mph	5.2	Yes ( $p < 0.001$ )	6.0	Yes ( $p < 0.001$ )	3.9

**Table 16 Saint Albans (Interstate 89 Southbound) at Bridge 91 Percentage of Traffic Exceeding Speed Limit**

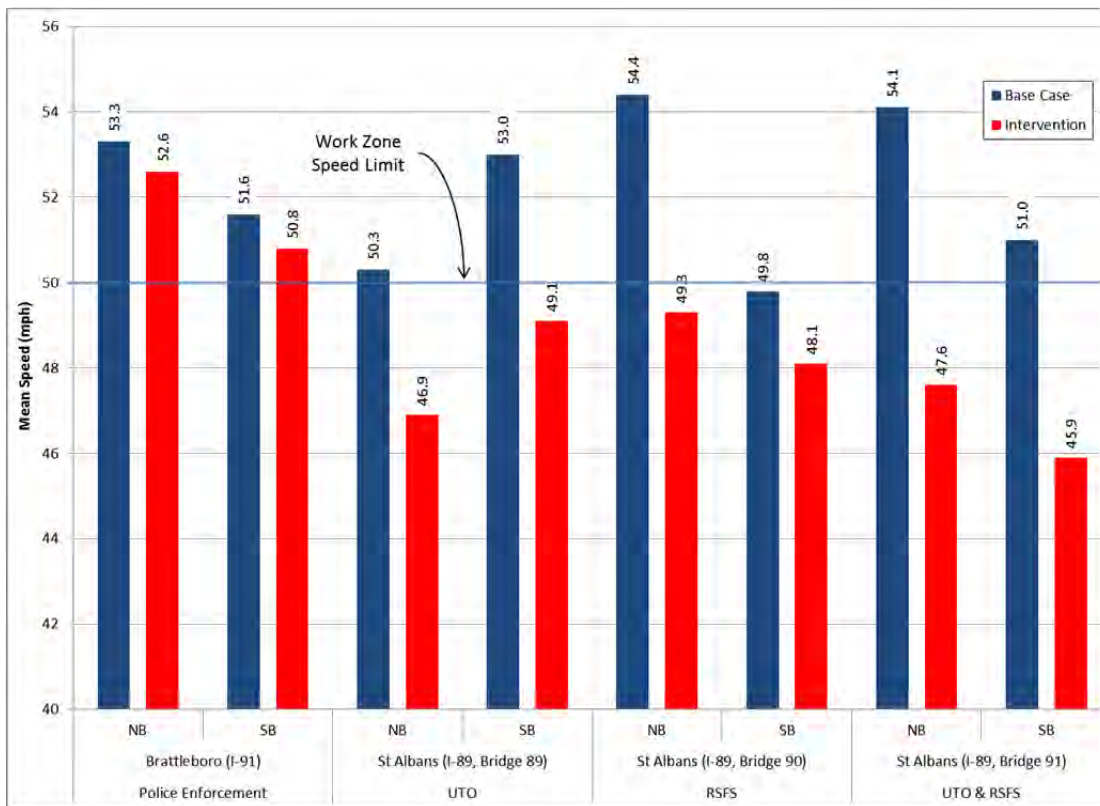
Southbound Location	Before UTO & RSFS: Percentage of Traffic (%)	Before/During Percentages: Statistically Different?	During UTO & RSFS: Percentage of Traffic (%)	During/After Percentages: Statistically Different?	After UTO & RSFS: Percentage of Traffic (%)
<b>iCone SB1 (upstream from work zone)</b>					
Exceeding speed limit	37.9	Yes ( $p < 0.001$ )	43.8	Yes ( $p < 0.001$ )	37.3
Exceeding by >5 mph	8.7	Yes ( $p < 0.001$ )	12.3	Yes ( $p < 0.001$ )	10.6
<b>iCone SB2 (in work zone)</b>					
Exceeding speed limit	24.3	Yes ( $p < 0.001$ )	2.1	Yes ( $p < 0.001$ )	10.7
Exceeding by > 5 mph	2.5	Yes ( $p < 0.001$ )	0.2	Yes ( $p < 0.001$ )	1.0
<b>iCone SB3 (downstream from work zone)</b>					
Exceeding speed limit	50.9	Yes ( $p < 0.001$ )	49.0	Yes ( $p < 0.001$ )	48.7
Exceeding by >5 mph	19.6	Yes ( $p < 0.001$ )	19.8	Yes ( $p < 0.001$ )	19.5

## 5. Conclusions

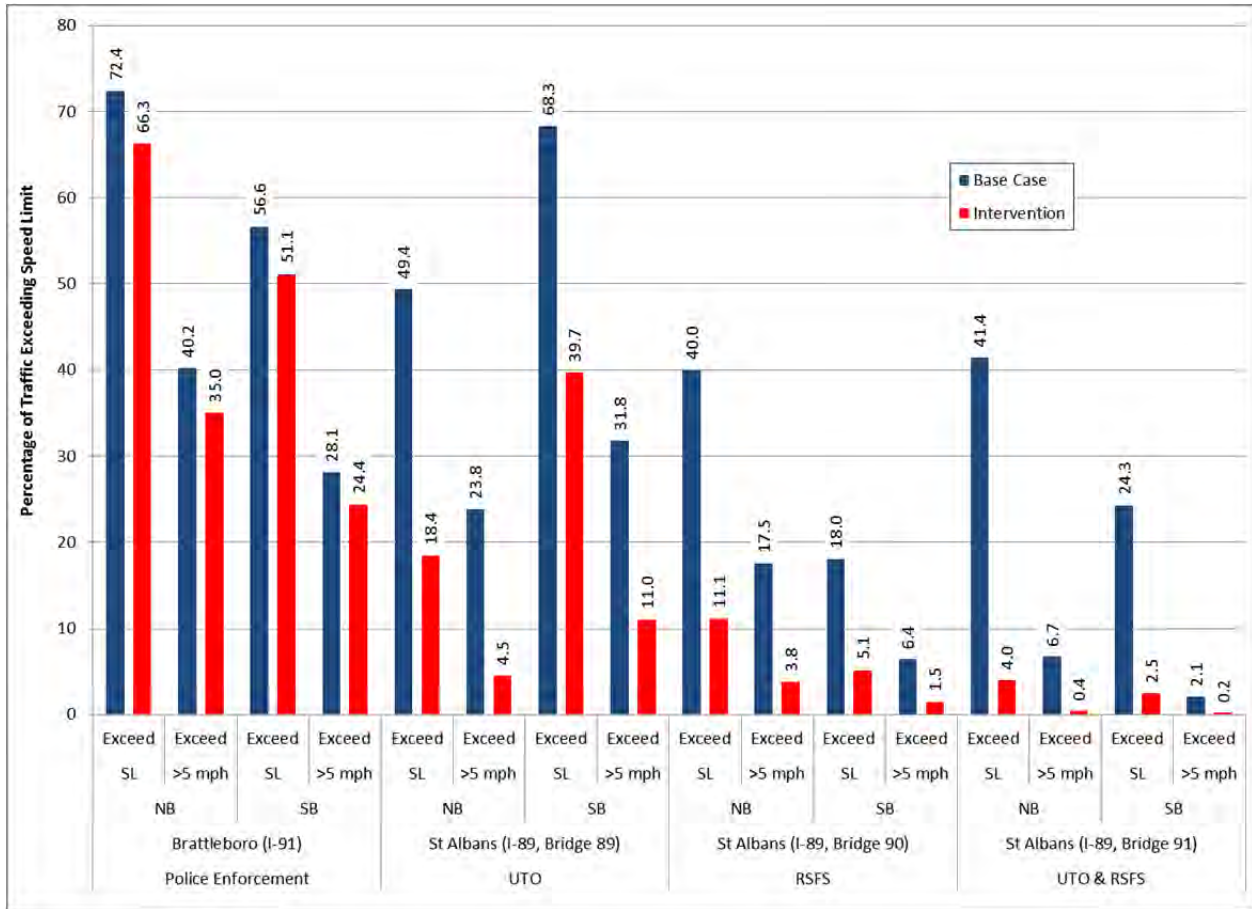
In total, five types of interventions were examined in this project to assess the impact of each on traveler speeds at various work zones on different types of roadways. They include:

1. The use of UTO at selected periods when the work zones are active (on an interstate highway);
2. Targeted police enforcement of speeds at selected periods when the work zones are active (on a two-lane, two-way state highway and an interstate highway);
3. The use of flaggers to direct traffic and manage lane closures (on a two-lane, two-way state highway);
4. The deployment of RSFS that post the work zone speed limit, as well as detect and display the travel speeds of approaching vehicles (on an interstate highway); and
5. The combination of both UTO and RSFS (on an interstate highway).

Figures 12 and 13 below summarize the impacts of police enforcement, UTO, and RSFS on traveler speeds for the interstate highway facilities.



**Figure 12 Mean Speed of Traffic by Intervention** (Note that “Base Case” refers to *without police enforcement* for Brattleboro and the *before-intervention* period for the three other locations in St Albans.)



**Figure 13 Percentage of Traffic Exceeding the Speed Limit (SL) by Intervention** (Note that “Base Case” refers to *without police enforcement* for Brattleboro and the *before-intervention* period for the three other locations in St Albans.)

In terms of mean speeds and the proportion of traffic that exceeded the speed limit, the least effective intervention was targeted police enforcement. In both the Richmond and Brattleboro projects, there were significant drops in mean speeds and the percentages of speeders in the work zones but they all remained relatively high. In the Richmond case (a two-lane, two-way state highway), the proportion of speeders who exceeded the speed limit by more than 5 mph remained at 13% during periods when there were police enforcement activities. In the Brattleboro case (an interstate highway), those proportions were even higher; they were 35.0% for the northbound direction and 24.4% for southbound. The mean speeds in the work zones in both locations remained above the speed limit. It is very likely that all these numbers remained high at these locations because not all vehicles were exposed to the intervention. While some local travelers who frequented these routes during the construction periods may have known that there were periodic police enforcement activities, the lack of direct exposure to a police presence for all travelers may have led to a significant number of people who chose not to comply with the speed limit. This may be particularly true for the Richmond case since the

average length of a police enforcement period was only 11 minutes, which may not be enough to convince the daily commuters that apprehension was likely.

In the case of the flaggers and the lane closures, there appears to be a spatial relationship with the impact of the travel speeds. In light volume conditions where there are no significant backups, the impacts are localized within a distance of approximately 3000 feet. From the data gathered at the Addison-New Haven project, it was not possible to determine what impacts, if any, flaggers would have on traveler speeds if no lane closures were present.

For the remaining interventions, it appears that the use of UTO and RSFS were similarly effective in lowering mean speeds and the proportion of travelers who exceed the speed limit. When deployed alone, both of these interventions were able to bring the mean speeds to below the work zone speed limit. They were also both effective in dramatically decreasing the proportion of speeders, in terms of the percent of vehicles who were over the speed limit and those who were at least going 5 mph faster than the limit.

When combined, the use of both UTO and RSFS appears to have compounding impacts on traveler speeds through work zones. The mean speeds were significantly lower than the work zone speed limit and those at the locations where only one intervention was applied. As such, the proportions of speeders who exceeded the speed limit in the work zone were very small. The percentages were close to zero for those who were speeding more than 5 mph.

## 6. References

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Antonucci, N. D., J. E. Bryden, T. R. Neuman, R. Pfefer, K. Slack (2005). *National Cooperative Highway Research Program Report 500, Guidance for Implementation of the AAHSTO Strategic Highway Safety Plan, Volume 17: A guide for reducing work zone collisions*. Washington, D.C.: Transportation Research Board.

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_500v17.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v17.pdf) Accessed 15 Aug 2011.

Bloch, S. (1998). Comparative Study of Speed Reduction Effects of Photo-Radar and Speed Display Boards. *Transportation Research Record* 1640.

Bowie, J. M. (2003). *Efficacy of Speed Monitoring Displays in Increasing Speed Limit Compliance in Highway Work Zones*. Thesis, Department of Civil and Environmental Engineering, Brigham Young University, Provo, UT.

Brewer, M. A., Pesti, G., Schneider, IV, W. H. (2005). *Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance*. Texas Transportation Institute, College Station, TX.

FARS (Fatality Analysis Reporting System) (2011). *FARS Encyclopedia Query Tool*. National Highway Traffic Safety Administration. <http://www-fars.nhtsa.dot.gov/QueryTool/> Accessed 15 Aug 2011.

Garber, N. and Zhao, M. (2002). *Crash Characteristics at Work Zones*. Virginia Transportation Research Council. Charlottesville, VA.

Mattox, III, J., W. Sarasua, J. Ogle, R. Eckenrode, A. Dunning. (2008). Development and Evaluation of a Speed-Activated Sign to Reduce Speeds in Work Zones. Present at the Transportation Research Board Annual Meeting.

NCHRP (National Cooperative Highway Research Project) (2005). *A Guide for Reducing Work Zone Crashes*. Washington, D. C.: Transportation Research Board.

<http://safety.transportation.org/doc/WorkZone%20Rev1-3.pdf> Accessed 15 Aug 2011.

Pesti, G., and McCoy, P. T. (2001). Long-Term Effectiveness of Speed Monitoring Displays in Work Zones on Rural Interstate Highways. *Transportation Research Record* 1754.

Ullman, G. L., Brewer, M. A., Bryden, J. E., Corkran, M. O., Hubbs, C. W., Chandra, A. K., Jeannotte, K. L. (2013a). *National Cooperative Highway Research Program Report 746: Traffic Enforcement Strategies for Work Zones*. Transportation Research Board of the National Academies.



Ullman, G. L., Brewer, M. A., Bryden, J. E., Corkran, M. O., Hubbs, C. W., Chandra, A. K., Jeannotte, K. L. (2013b). *National Cooperative Highway Research Program Web-Only Document 194: Traffic Enforcement Strategies for Work Zones: Phase II Research*. Transportation Research Board of the National Academies.

Wang, C., Dixon, K. K., Jared, D. (2003). Evaluating Speed-Reduction Strategies for Highway Work Zones. *Transportation Research Record* 1824.