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16. Abstract

The Texas Department of Transportation (TxDOT) has placed improving safety as one of its top objectives. Improving safety in rural intersections is a means to improve roadway safety especially in rural districts such as the districts in West Texas. The Texas A&M Transportation Institute (TTI) in consultation with TxDOT engineers developed a low-cost system that can be configured with off the shelf components and can be installed fairly easily. The system uses wireless sensors to complete contact closures in a cabinet that was built by TTI researchers to activate beacons on the Stop sign and Stop Ahead sign when a vehicle is arriving on a stop-controlled approach. The system also would keep the beacons on the Stop sign flashing till the vehicle at the Stop Bar leaves the intersection. The system was demonstrated at the Pecos Test Track. A TxDOT expert panel reviewed the system both during daytime and nighttime. The expert panel was overall supportive of the system, made some recommendations for improving the system, and was interested in implementing the system in their districts. The system was implemented at an intersection near Pecos. Based on panel's recommendation a system that would activate the beacons on the Stop sign if vehicle speed is above a user defined threshold was also designed, implemented, and demonstrated to the district engineers.

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IMPROVEMENTS TO RURAL INTERSECTIONS TO IMPROVE MOTORIST COMPLIANCE

by

Srinivasa Sunkari
Research Engineer
Texas A&M Transportation Institute

Report 9-1529-1
Project 9-1529
Project Title: Low-Cost Safety Solutions, Pavement Preservation and Maintenance Practices for Rural Highways

Performed in cooperation with the
Texas Department of Transportation
and the
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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). 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 FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Srinivasa R. Sunkari, P.E., # 87591.

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INTRODUCTION

In the United States, intersections constitute a small portion of the highway system, yet intersection-related crashes constitute more than 50 percent of all crashes in urban areas and 30 percent in rural areas. In Texas, about one-third of all crashes on rural highways occur at intersections. As population and development increases, traffic at unsignalized intersections grows, resulting in more crashes. This is particularly the case in rural intersections that are characterized by high speeds. The combination of high speeds, complex guidance, and navigational choices at rural intersections complicate the driving task and increase the potential for a severe crash. Various design and traffic control device (TCD) improvements are implemented to decrease the likelihood of a crash.

This project developed and demonstrated innovative low-cost solutions to improve safety at stop-controlled intersections. Texas A&M Transportation Institute (TTI) researchers met with the Texas Department of Transportation (TxDOT) project panel and obtained feedback about potential solutions that the panel wanted TTI to investigate. Preliminary directives from the panel were:

1. Focus on treatments on the minor street approach and not necessarily on the major street approach.
2. Develop solutions to improve the ability of the motorist to perceive the intersection as well as the related TCDs as they approach the intersection.
3. Investigate solutions that are active in nature, i.e., have beacons come on when a vehicle arrives or when a vehicle is not slowing down.

The emphasis in this project was on testing and demonstrating newer and innovative solutions. These included solutions that were not readily available in the market but could be configured relatively easily using off the shelf equipment. TTI researchers in this project are also currently participating in another TxDOT Research Project 0-6462, which is titled “Evaluation of Modern Traffic Control Devices to Improve Safety at Rural Intersections” led by Kay Fitzpatrick. A literature survey was conducted as part of project 0-6462. This report extracts a significant amount of information gathered and documented in Project 0-6462 with respect to TCD alternatives to improve safety at rural intersections.

TRAFFIC CONTROL DEVICE ALTERNATIVES

Several TCD alternatives are available and are being used at rural, stop-controlled intersections to improve safety at these intersections. They can be categorized as improvements to Stop signs such as increasing the size of the signs, improving reflectivity, adding beacons and Light Emitting Diodes (LEDs), adding advance warning signs on minor street approaches and on major street approaches, and overhead beacons at intersections. Some of these improvements are vendor specific while others are generic.

ENHANCEMENT TO THE STOP SIGN

Numerous enhancements have been tried out to improve the effectiveness of stop signs. These included improvements to the sign itself, such as increasing the size of the sign, improving the retroreflectivity, adding a second Stop sign at the intersection, adding a Stop Ahead sign, adding beacons to the signs, and using embedded LEDs within the sign. A survey of TxDOT districts found that districts that increase the size of the Stop sign as the first low cost treatment can also include pavements markings on the intersection approach. Previous studies have reported the effectiveness of these treatments.

A field observational test of increasing the size of Stop signs showed that drivers, especially older drivers, braked at greater distances for the largest sized Stop sign (*1*). A recent Federal Highway Administration (FHWA) study conducted a safety evaluation of increasing retroreflectivity of Stop signs using before-after data from South Carolina and Connecticut (*2*). The aggregate analysis indicated that higher retroreflectivity may affect the likelihood of crashes at unsignalized intersections, but the effect was not detectable with the study design and available sample size. The disaggregate analysis concluded that installations at all three-legged intersections were found to have a statistically significant reduction in crashes. The disaggregate analysis also showed that the strategy is more effective at lower volumes for motorists approaching the intersection on the minor road.

Arnold and Lantz evaluated the use of flashing LED Stop sign and optical speed bars at three locations in Virginia (*3*). The study showed a statistically significant decrease in approach speeds at the study sites, but questioned the practical significance of the decrease. The speed reductions were observed to be greater during dusk and nighttime. The study recommends the device as a potential countermeasure for accident-prone stop-controlled intersections. Installation of optical bars also saw statistically significant decrease in approach speeds. The study reports that speed decreases were higher when the bars extended across the travel lane. Figure 1 shows an example of optical bars approaching an unsignalized intersection.

Figure 1. Example of Optical Bars (*3*).

USE OF LIGHT EMITTING DIODES IN STOP SIGNS

The effectiveness of flashing LED Stop signs was studied at two locations in 2004 by analyzing before and after speed data and Stop sign compliance (*4*). The overall rate of vehicles not fully stopping was reduced by 29 percent after installation of the flashing LED Stop sign. The flashing signs resulted in no statistically significant effect on vehicular speeds or decelerations on the approaches. The study recommended the use of the flashing LED Stop signs as a special treatment on an as needed basis.

Houten and Retting compared effectiveness of using a LED sign that featured animated eyes scanning left and right to prompt drivers to look left and right for approaching traffic with a Look Both Ways supplemental plaque (Figure 2) at three sites (*5*). The results indicated that introduction of the animated eyes prompt increased the percentage of vehicles coming to a complete stop at all the study sites, whereas, the Look Both Ways sign was not associated with any change in behavior at the one site it was introduced. However, the authors recommended further research to understand sustainable benefits of the improvement.

Figure 2. Look Both Ways Prompt and the Animated Eye Prompt (*8*).

ADVANCE WARNING OF STOP USING BEACONS

Zwahlen found that drivers at night approached a stop-controlled intersection at lower speeds when a Stop Ahead text sign was present. The advance warning sign had no noticeable effect on eye glance behavior at night or during the day (*6*). Hawkins et al. conducted a survey of 1,745 Texas drivers to assess their comprehension of selected traffic control devices. The survey for comprehension of the Stop Ahead symbol sign (W3-1a of the Manual on Uniform Traffic Control Devices [MUTCD]) indicated that 87 percent of the drivers understood the sign (*7*). Figure 3 shows an example of the Stop Ahead symbol warning sign.

The addition of a yellow beacon on a Stop Ahead or Intersection Ahead Sign is believed to improve the conspicuity of the advance warning sign. Figure 4 shows an example of an advance warning sign with yellow flashing beacon.

Figure 3. Stop Ahead Symbol Warning Sign. Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 4. Example of Yellow Beacon on Advance Warning Stop Sign.

Several studies have examined advance warning signs with beacons for high-speed signalized intersections (*8*, *9*, *10*, *11*). A late 1990s study used 106 intersections to identify the effects of advance warning flashers (AWFs) (8). The results from the study indicated that intersections equipped with AWFs have a lower frequency of crashes than similar locations without AWFs. However, the results were not statistically significant. A mid-1990s study found that the impacts of the different signs vary among intersections with tangent and curved approaches (9). The study showed that the Prepare to Stop When Flashing (PTSWF) and Flashing Symbolic Signal Ahead (FSSA) signs generally has similar effects on driver behavior. The authors recommended using the Continuously Flashing Symbolic Signal Ahead (CFSSA) sign before using the PTSWF sign because the PTSWF and FSSA signs had undesirable effects on vehicle speeds. When flashers are off and the signal indication was green or yellow, drivers on an approach with PTSWF or FSSA sign generally increase their speed in an apparent attempt to beat the light. This behavior is particularly more evident on intersections with a tangent approach than on intersections with a curved approach because the roadway curvature provides restrictions to the drivers on the selection of their speed.

Two research projects sponsored by TxDOT have developed and made improvements to an Advance Warning of End of Green System (AWEGS) (*12*). AWEGS is unique from other systems with AWFs in that it maintains the existing dilemma zone protection provided by intersection detectors and enhances it by providing an advance warning about the termination of green. Traditional AWF systems could not provide the existing dilemma zone protection provided by the intersection detectors. AWEGS have been installed at seven intersections in Texas and more are being planned. AWEGS have reduced red light running at most intersections by about 40 percent.

ADVANCE WARNING ON MAJOR STREET

Advance Warning for Intersection Ahead Sign is another TCD used to warn major road users to expect cross traffic. Figure 5 shows an example of Intersection Ahead warning sign for major roads.

Stokes et al. identified factors that contribute to crashes at two-way stop-controlled intersections and determined TCDs or other measures could be effective in reducing the frequency of these crashes (*13*). They concluded that the disregard for Stop signs and other TCDs is not the primary cause of crashes at rural two-way stop-controlled intersections. The majority of the crashes appear to be due to drivers who enter the major roadway and do not (or cannot) accelerate quickly enough to avoid being struck by major roadway vehicles. This would suggest that drivers on the minor roadway either did not see oncoming vehicles or failed to accurately estimate the speeds of oncoming vehicles on the major roadway. On the basis of these conclusions they recommended that the Kansas Department of Transportation consider implementing signing treatments directed at reducing the speeds of motorists on the major roadway. Figure 6 shows an example of Reduced Speed Ahead warning sign.

INTERSECTION CONTROL BEACONS

Intersection Control Beacons are used in conjunction with Stop signs at isolated intersections or intersections having sight distance obstructions. Research findings recommend that they not be used at “Y,” offset, or intersections with more than four legs because the geometry of these intersections frequently does not provide an adequate line of sight from all intersection legs to a center-mounted beacon. Figure 7 shows examples of intersection control beacons.

Several previous studies have examined intersection control beacons. A late 1990s study used two to three years of crash data to analyze right-angle crashes at seven beacon-controlled intersections (*14*). The data showed a decrease in fatal and serious injury crashes and an increase in minor visible injury and property-damage-only crashes. However, none of these results were statistically significant; therefore, the results were determined to be inconclusive.

Stackhouse and Cassidy (*15*) used surveys to obtain a driver’s understanding of overhead and sign-mounted beacons. Drivers indicated that they were more likely to come to a full stop when red overhead flashing beacons were present than for pedestal-mounted red flashers on Stop signs. Approximately one-third of drivers stated that under some conditions they had been confused by the meaning of flashing lights. About 38 percent of young drivers and 46 percent of older drivers believed that if an overhead flashing red light was present for the minor approach, an overhead flashing light was also present for the major approach. They concluded that this may lead drivers to assume that the major road traffic stops in all cases when a flashing red overhead beacon is present. They also conducted an analysis using crash experience for three years before and three years after the installation of overhead flashing beacons at eight intersections in Minnesota (*15*). Overall, there was a 39 percent reduction in crashes after the installation of overhead flashers, varying from a 4 percent increase to a 63 percent decrease in crashes.

Figure 5. Example of Intersection Ahead Warning Sign for Major Road.

Figure 6. Reduced Speed Ahead Warning Sign for the Major Road.

Source: http://www.trafficsign.us/650/warn/w3-5.gif

Source: http://www.tfhrc.gov/safety/pubs/08048/index.htm

Source: http://tti.tamu.edu/documents/4048-2.pdf

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 7. Examples of Intersection Control Beacon.

Because of concerns that the beacons were giving the false perception that all the flashers were red, the Minnesota Department of Transportation is replacing the four-headed overhead flashing beacons with red flashing beacons mounted on the minor road Stop sign and a yellow flashing beacon mounted on the appropriate intersection warning sign for the major approach (*16*). The effectiveness of the practice is to be evaluated as part of a pooled fund study per a 2006 *Public Roads* article (*16*). Figure 8 illustrates examples of the sign-mounted beacons being used to replace overhead flashing beacons.

Source: http://www.tfhrc.gov/pubrds/06jul/08.htm

Source: Hallmark et al. (*17*)

Figure 8. Examples of Replacement Beacons for Overhead Flashing Beacons.

A recent FHWA study evaluated the safety effectiveness of flashing beacons at stop-controlled intersections (*18*). Three types of flashing beacons—intersection control beacons, beacons mounted on Stop signs, and actuated beacons—were considered collectively at stop-controlled intersections. Although these could be considered three distinct safety strategies with different expected performance, due to sample size limitations, they were analyzed collectively in the study. The study included 64 sites in North Carolina and 42 sites in South Carolina, and the Empirical Bayes study method was used in the evaluation. For the combined results the following estimates of reduction in crashes per site-year was found to be statistically significant:

- 21 percent angle.
- 15 percent injury and fatal.

The disaggregate analysis found:

- Flashing beacons seem to be more effective at rural and suburban locations.
- Beacon types include standard beacons where the beacon flashes all the time and actuated beacons. Some of the actuated flashers are supplemented with a sign that reads, "Vehicle Entering When Flashing." Standard beacons can be located overhead or on a Stop sign. There seems to be a significant reduction in crashes at sites with standard beacons mounted on Stop signs. However, only five sites belonged to this category, and so, it was not possible to make definitive conclusions regarding beacon location.

The economic analysis based on the combined results for angle and non-angle crashes from both states indicates that standard flashing beacons and some of the actuated ones (i.e., the less expensive beacons) are economically justified, but that a benefit cost ratio of 2:1 may not be achievable for the more expensive actuated beacon types.

INTERSECTION DECISION SUPPORT

Rural Intersection Decision Support is a new system being considered for improving the driver's ability to successfully negotiate rural intersections. The system identifies safe gaps and communicates this information to the driver uses sensing and communication technology (*19*). A simulator based evaluation was used to test the information concepts of the designs. Table 1 shows a matrix of interface concepts highlighting information elements and role of driver.

According to the study, the informational content of Icon and Countdown signs was best understood by drivers, and most of them were reported to be using information from these signs while making crossing decisions. The authors also noted that the signs would have to be altered to be included in the MUTCD and that safe gaps individualized to the driver may increase the usability of the signs' content, which needs to be evaluated.

A similar intersection collision avoidance warning system was evaluated by the Maine Department of Transportation at rural stop-controlled intersections with severe sight distance limitations (*20*). The signs warn drivers waiting at the Stop signs on the minor approaches when traffic is approaching from either direction. Another warning sign located on the major approach with limited sight distance warns drivers approaching the intersection when a vehicle is waiting at the Stop signs on the minor approaches. The preliminary study concludes that the signs seem to be fairly well understood. The minor approach drivers used much longer gaps after the installation. Additionally, the number of traffic conflicts was reduced by 35 to 40 percent; however, the highway capacity was also reduced and greater delays were experienced.

Table 1. Matrix of Interface Concepts (*19*).

	No Support	Hazard Detection	Gap Information		
	Baseline	Alert	Display	Warn	Advise
Design Concept	STOP Sign (no support)	Hazard Sign	Countdown Sign	Icon Sign	Variable Message Sign (VMS)
					
Driver Role	Driver recognizes hazard, gathers information, decides on safety condition and chooses action.	Driver gathers information, decides on safety condition, and chooses action.	Driver decides on safety condition and chooses action.	Driver must choose action.	Driver chooses to comply.
System Role		System detects hazard and provides alert.	System detects hazard and presents information relevant to vehicle gap. Prohibited actions also indicated.	System detects hazard and provides warning levels based on gap information. Prohibited actions also indicated.	System displays prohibited actions (unsafe action advisory).

SAFETY

In a study on nighttime crashes (*17*), the authors reported on the progressive approach used by Pierce County, Washington. Pierce County recommends that the least aggressive approach should be considered first in addressing crash problems at rural intersections according to the following ascending order of invasiveness:

1. Install Stop Ahead signs.
2. Increase the size of Stop and Stop Ahead signs.
3. Install transverse rumble strips.
4. Install overhead flashing beacons with illumination.

Hochstein et al. (*21*) on rural expressway intersections categorized intersection safety treatments into three groups:

- Conflict point management – treatments that remove/reduce, relocate, and/or control the 42 conflict points that occur at a traditional two-way, stop-controlled rural expressway intersection.

- Gap selection aids – countermeasures that are intended to aid a driver in selecting a safe gap into or through the expressway traffic stream.
- Intersection recognition devices – countermeasures that are intended to enhance intersection conspicuity for either minor road or expressway drivers.

A review of Minnesota's crashes for rural two-lane highway intersections by Preston and Storm (*22*) focused on identifying predominate crash types. They concluded that strategies are needed to address the issue of gap selection and intersection recognition. They observed that due to the very low frequency of occurrence of either type of crash, the most effective implementation would most likely involve a systematic approach instead of an approach focused on the very small number of locations with multiple crashes.

Retting et al. (*23*) developed a better understanding of the crashes that occur at Stop signs and identified potential countermeasures. Police reports of crashes at stop-controlled intersections during 1996–2000 in four U.S. cities were examined in detail. At total of 1,788 crash reports for intersections with two-way Stop signs were included in the study. Stop sign violations accounted for about 70 percent of all crashes. Typically these crashes were angular collisions. Among crashes not involving Stop violations, rear-end crashes were most common, accounting for about 12 percent of all crashes. Stop sign violation crashes were classified into several subtypes: driver stopped, driver did not stop, snow/wet/ice, and other/unknown. In about two-thirds of Stop sign violation crashes, drivers said they had first come to a stop. In these cases, inability or failure to see approaching traffic often was cited as the cause of the crash. Drivers younger than 18 and drivers 65 and older were disproportionately found to be at fault in crashes at Stop signs. Potential countermeasures included changing traffic control and intersection design, improving intersection sight distance, and increasing conspicuity of Stop signs through supplemental pavement markings and other devices

SYSTEM OBJECTIVES

Based on the review of the literature and the practices adopted by other agencies across the countries, the TxDOT research panel made the following recommendations to develop a system:

1. The system should improve the compliance of motorists on the minor street approaches of a stop-controlled intersection.
2. The system should not provide any information to the motorists on the stop-controlled approach about the presence of vehicles on the major street.
3. The system should not make any recommendations to the stopped motorists about when to enter the intersection.
4. The system should improve the attention value of the TCDs on the stop-controlled approach.
5. The system should consider making the TCDs active in nature to improve the attention value, for example, by activating the beacons only when vehicles arrive on the approach.
6. The system should consider increasing the attention values of the TCDs if the motorists are detected to not comply with the sign, i.e., start flashing the beacons if the vehicles are not slowing down on the approach.

These were the guidelines provided to the research team to develop a system to improve the safety on rural stop controlled intersections.

SYSTEM DESIGN

To be consistent with the directives of the panel, TTI researchers developed the following sign/system configurations to be deployed and demonstrated. These configurations illustrate the improvements to traffic control on the minor street approaches by making them more active in nature. Prior projects (0-6462) had evaluated internally illuminated Stop signs. This project made modifications to these signs.

Alternative 1

The first alternative considered was internally illuminated Stop signs operating in an active manner. K&K Signs and TAPCO signs were operated in an active manner using a pair of wireless Sensys detectors as illustrated in Figure 9. Wireless sensors were located at a distance of approximately 1,000 feet from the intersection. TTI proposed to use Sensys wireless sensors to develop this system as researchers had some experience using them and could get some sensors on a loan basis while developing the system. Sensys sensors detect the vehicles traveling over the sensors and transmit the actuation using a repeater located near the sensors to the Access Point near the Stop sign. A flasher panel that has already been fabricated receives the actuation from the Access Point to trigger the Active Stop signs, as illustrated in Figure 10. Figure 11 illustrates a completely fabricated flasher panel. Figure 12 illustrates four Sensys Sensors and an Access Point for Sensys Sensors. The described methodology can be applicable for the K&K signs. The TAPCO signs may require a customized actuation, because the signs are not triggered by contact closure but by serial communication. TAPCO has a configuration to implement an active Stop sign based on the presence of a vehicle. However, TTI researchers will not test the TAPCO signs due to their proprietary firmware to operate the beacons.

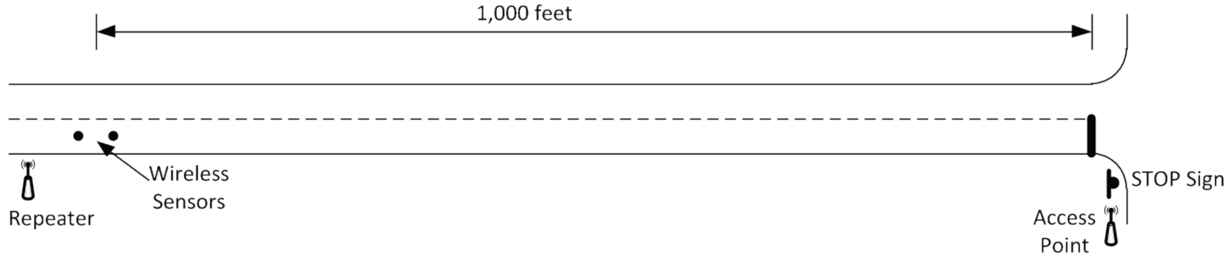

Figure 9. Alternative 1 – Internally Illuminated Active Stop Signs (K&K and TAPCO).

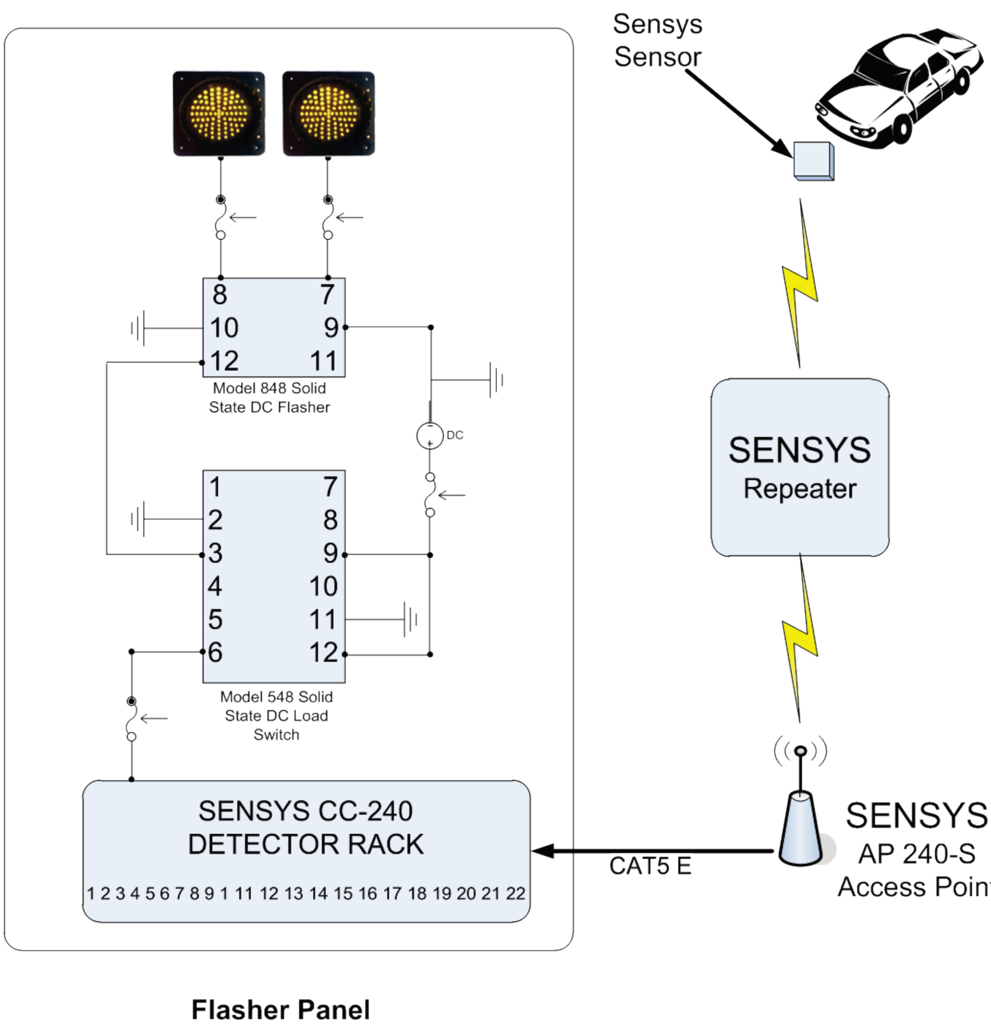

Figure 10. Sensor-Flasher Panel Configuration.

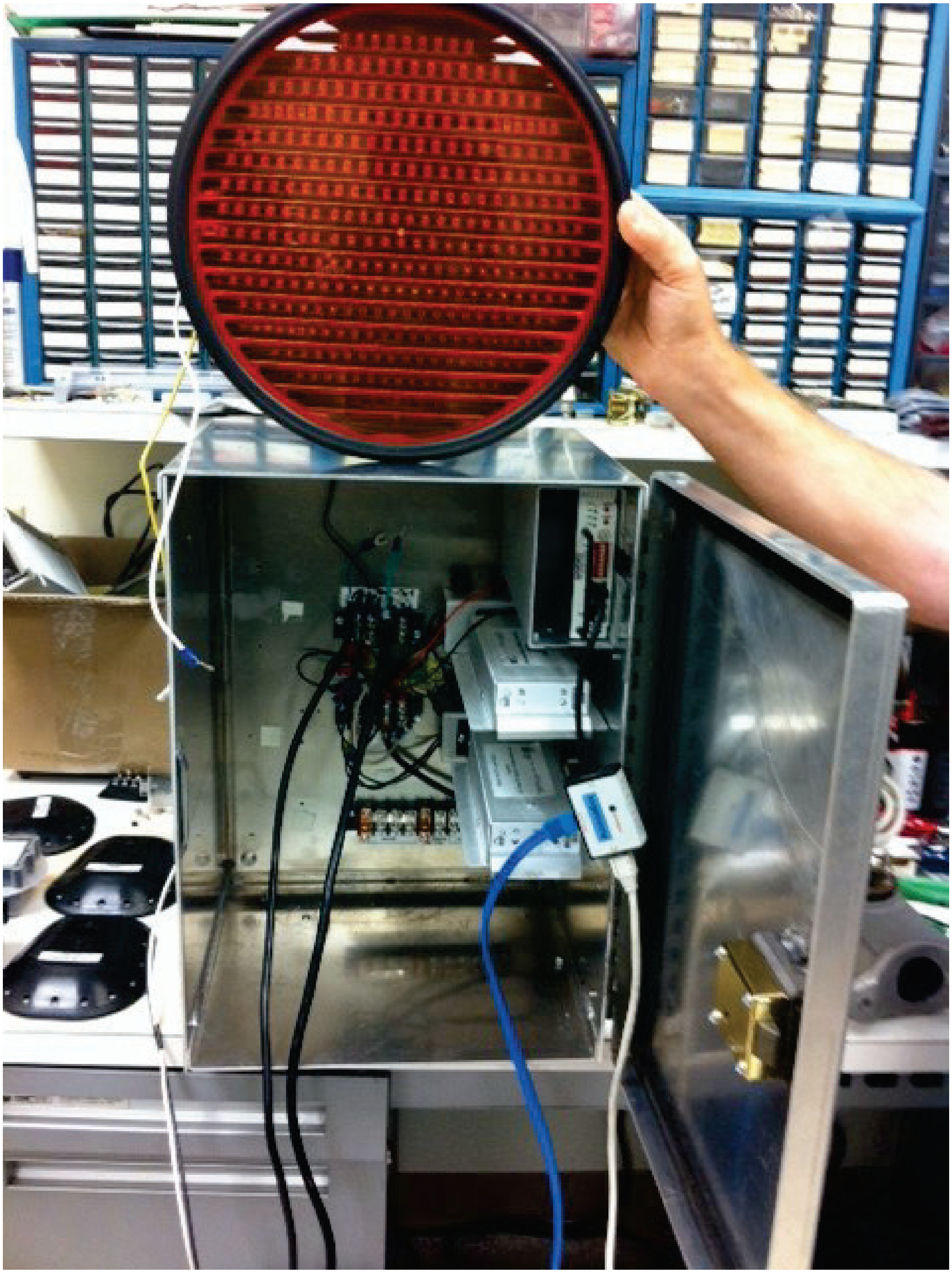

Figure 11. A Fabricated Flasher Panel to Control the Beacons Using Sensys Sensors.

Figure 12. Four Sensys Sensors and an Access Point Necessary to Operate the Beacon.

Alternative 2

Alternative 2 was comprised of a typical 36 inch Stop sign with beacons and a 36 inch Stop Ahead sign with beacons located about 550 feet from the intersection, as illustrated in Figure 13. The beacons on the Stop sign operated in a static mode, i.e., they were flashing all the time. However the beacons on the Stop Ahead sign operated in an active manner, i.e., the beacons activated only when a vehicle was approaching the intersection and traveled over the wireless sensors, which were located at a distance of about a 1000 feet from the intersection. The objective was for the beacons to start flashing (being active) when a vehicle actuated the sensors and the vehicle was about 450 feet from the beacons. The beacons were aimed at the pavement near the sensor location.

The hypothesis was that an active Stop Ahead sign has a higher attention value due to the active nature of the sign. Attention value can be defined as a subjective measure of the ability of the TCD to attract the attention of a motorist. For an approach speed of 60 mph, the vehicle will take approximately five seconds to pass the Stop Ahead sign. The beacon control cabinet illustrated Figure 11 was be configured so that the beacons would continue to flash for a period of time (pre-determined) to ensure that the vehicles were past the Stop Ahead sign.

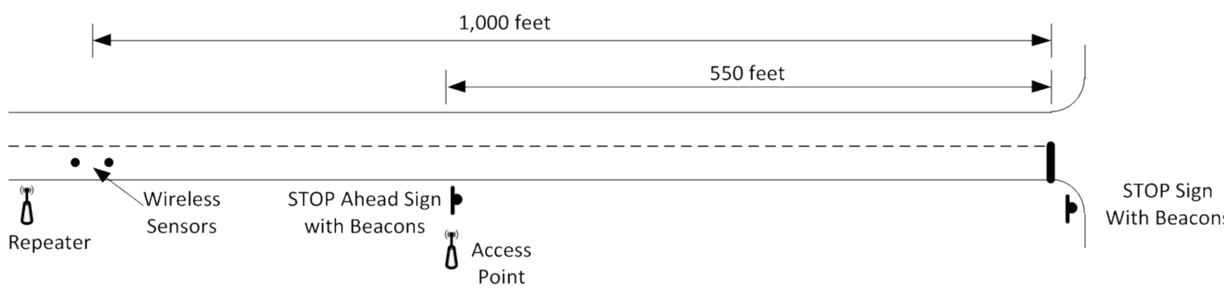

Figure 13. Active Stop Ahead Sign with Beacons with Static Stop Sign with Beacons.

Alternative 3

Alternative 3 was comprised of a typical 36 inch Stop sign with beacons and a 36 inch Stop Ahead sign with beacons. The Stop Ahead sign was located about 550 feet from the intersection as illustrated in Figure 14. The beacons on the Stop sign and on the Stop Ahead sign operated in an active manner, i.e., the beacons on both the signs activated only when a vehicle was approaching the intersection and traveled over the wireless sensors located at a distance of about a 1000 feet from the intersection. The objective was for the beacons to start flashing (being active) when a vehicle actuated the sensors and the vehicle was about 450 feet from the Stop Ahead sign. The beacons on the Stop Ahead sign were aimed at the pavement near the sensor location. The hypothesis was that an active sign has a higher attention value due to the active nature of the signs. The beacons on the Stop Ahead sign continued to flash for a period of time till the vehicle passed the Stop Ahead sign. Another pair of wireless sensors were be placed at the Stop bar so that the beacons would continue to flash as long as a vehicle was stopped at the intersection.

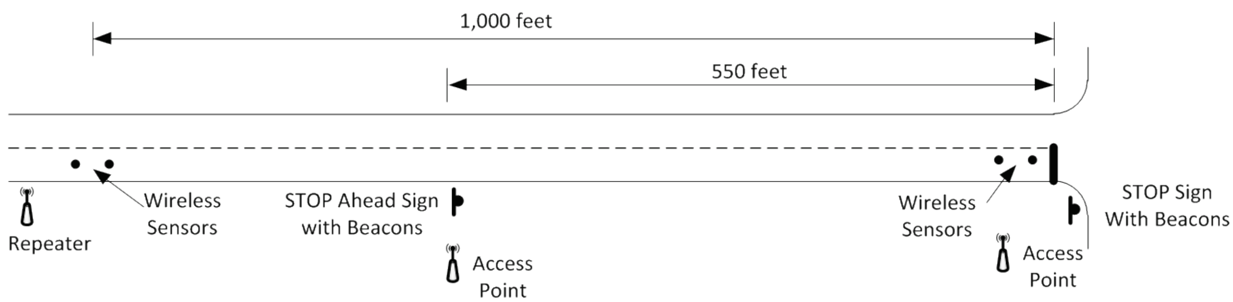

Figure 14. Active Stop Ahead Sign with Beacons with an Active Stop Sign with Beacons (Version 1).

IMPLEMENTATION OF THE TREATMENT

Treatment Installed

The treatment installed was a variation of Alternative 3 as described. Alternative 1 was not pursued as a prior study (*24*) did not find significant benefits in visibility of the K&K sign during daytime. The TAPCO sign on the other hand had good visibility during daytime and nighttime, but used custom software. Hence it was not possible to use the Sensys sensors with TAPCO to make it an active device. Researchers decided to use Sensys sensors due to their longer range with a repeater. Alternative 2, which was very similar to Alternative 3, only included the Stop Ahead sign as an active device. Researchers, however, felt that having an active Stop sign would have a more effective impact on the motorist's attention value and subsequently on driver compliance.

Alternate 3 was modified slightly and is illustrated in Figure 15. This device was comprised a typical 36 inch Stop sign with beacons and a 36 inch Stop Ahead sign with beacons. The Stop Ahead sign was located upstream of the intersection at a suitable location or as dictated by TxDOT's Sign Crew Field Book (*25*).

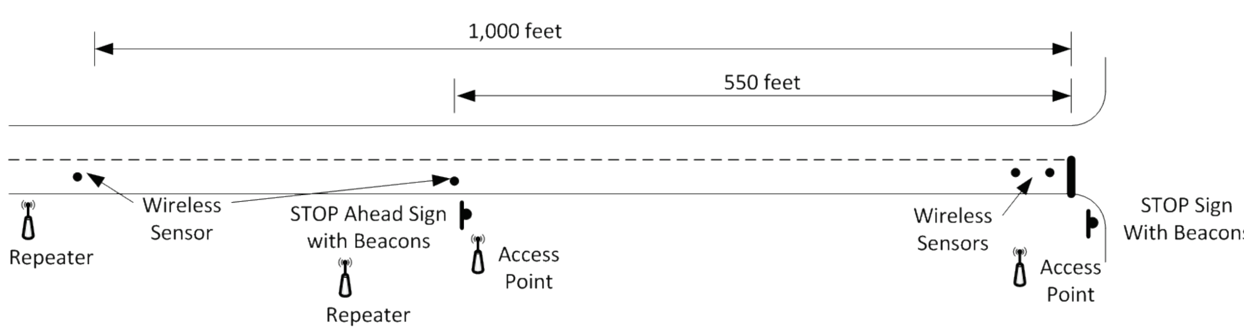

Figure 15. Active Stop Ahead Sign with Beacons with an Active Stop Sign with Beacons.

The treatment used wireless Sensys detectors. These detectors were magnetometer in nature and transmit vehicle actuation to the access point. When the detectors were located farther than 250 feet from an access point, a repeater was used to transmit the actuation to the access point, as illustrated in Figure 14. The access point then triggered the beacons to flash. The circuit diagram for the access point to trigger the beacons was illustrated in Figure 10.

TTI researchers configured two flasher cabinets and incorporated the circuit diagram illustrated in Figure 10. The flasher cabinet is illustrated in Figure 11. The other components of the treatment consist of Sensys sensors and access point. These are illustrated in Figure 12. In the installation at Pecos Test Track, the Access Point was installed on the same post as the sign and the beacons. The cabinet was powered by 12 volt batteries. For a complete installation at an intersection, the treatment was geared to use 12 volts from solar panels with minimal effort.

Installation at the Pecos Test Track

The Pecos Test Track is located about 20 miles to the south east of the city of Pecos and about 75 miles to the west of Odessa District Office. Figure 16 illustrates the location of the Pecos Test Track. Pecos Test Track consists of a 9-mile high speed (up to 200 mph) test track, a 10-mile road course, a skid pad, off-road courses, a 1.2-mile serpentine road among other facilities. An aerial photograph of the Pecos facility is illustrated in Figure 17.

The Pecos Test Track also has a 2000 feet two lane road at the entrance of the facility. TTI researchers visited the Pecos Test Track and selected this stretch to install the treatment. This stretch of the test track is illustrated in Figure 18.

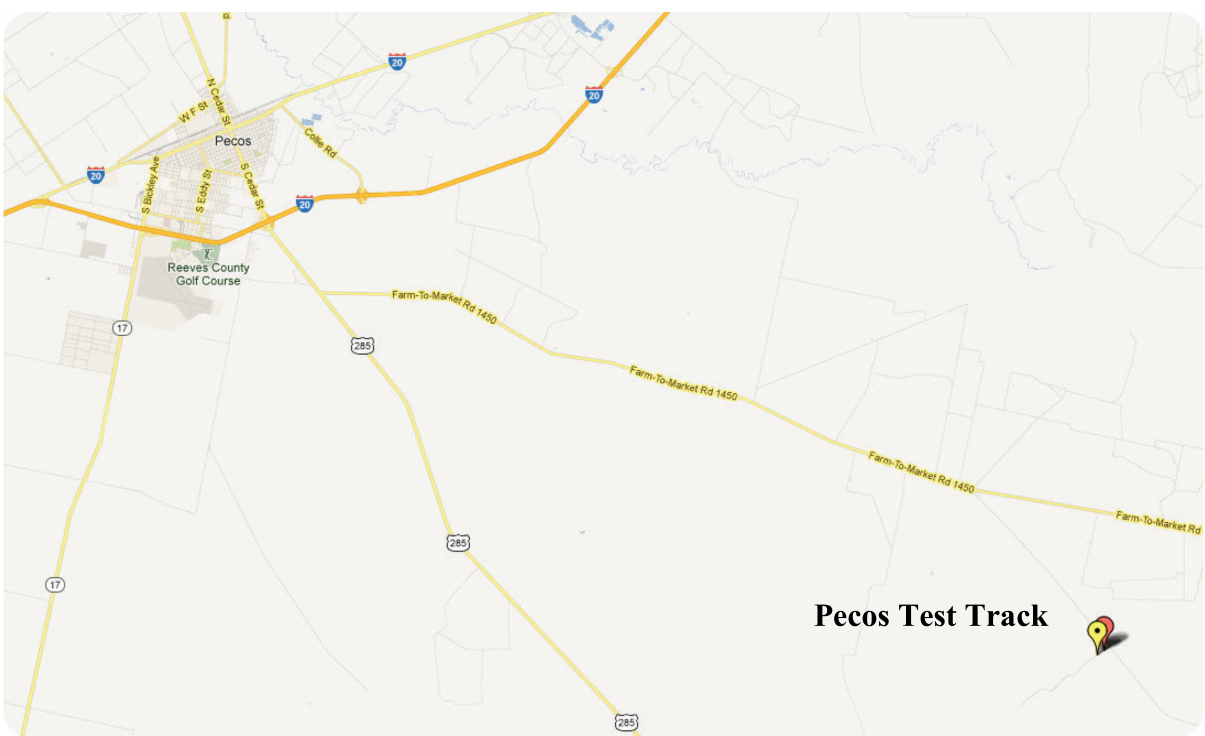

Figure 16. Location of Pecos Test Track (Courtesy Google Maps).

Figure 17. Pecos Test Track Overview (Courtesy Google Maps).

Figure 18. Layout of the Pecos Test Track Where the Treatment Was Installed (Courtesy Google Maps).

TTI researchers worked with the TxDOT Odessa District to install two roadside flashing beacon assemblies (RFBA). A Stop sign (R1-1) with red DC flashing beacons and a Stop Ahead sign (W3-1) with yellow DC flashing beacons were installed at the locations identified in Figure 18. Flasher cabinets fabricated by TTI researchers, Sensys Access Points, and repeaters were installed on the sign posts by TxDOT technicians. The two RFBA are illustrated in Figure 19 and Figure 20. One Sensys repeater was installed in the RFBA assembly for the Stop Ahead sign and the second one was installed on a temporary pole (Figure 21). Sensys sensors were placed on the pavement and vehicles driven over them. This facilitated exhibiting the functionality of the treatment and allowed TTI/TxDOT further use of the sensors in project. Solar panels were not installed as these signs were installed for a demonstration only. TTI researchers used 12 volt batteries to power the flasher cabinets and the beacons.

Figure 19. Stop Sign Installed at Pecos Test Track.

Figure 20. Stop Ahead Sign Installed at Pecos Test Track.

Figure 21. Sensys Sensors Used for the Treatment.

TREATMENT EVALUATION

An expert panel visit to the Pecos Test Track was scheduled in coordination by the Research and Technology Implementation (RTI) Office to evaluate the treatment. The panel consisted of the following TxDOT personnel:

1. Kelli Williams, Director Traffic Operations, Odessa District.
2. Roy Wright, Director Traffic Operations, Abilene District.
3. Gary Tarter, General Engineering Tech, Traffic Policy and Standards Group.

The expert panel started the first visit at 4 p.m. on July 8 to evaluate the treatment during daytime. After an hour of review, the panel visited the Pecos Test Track at 9:30 p.m. to review the treatment at night. The following are the general draft comments received by the TTI research team from the panel. These comments provided guidance for implementation of the current treatment and gave a roadmap for improvements to the treatment. TTI researchers solicited further comments from the expert panel and documented them in the final report.

- General comments:
    - Overall the treatment has the potential to improve the attention value of the drivers and is a good beginning.
    - It was simple to operate and relatively inexpensive to implement.
    - It was configured by over the shelf components.
    - While the treatment has marginal impact on attention value of the drivers during day time, it has a significant impact on the treatment during nighttime operations. However the attention value of the beacons can potentially be improved by aiming the beacons properly.
- Modifications required to the treatment demonstrated before installation at a real intersection:
    - The amber beacons on the Stop Ahead sign needed to be aimed properly to a spot on the roadway about 700 feet upstream of the beacons.
    - The 800 feet spacing between the advance detector and the amber beacons on Stop Ahead sign was adequate for implementation.
    - The 450 feet spacing between the Stop Ahead sign and Stop sign was too small. Normal spacing between these traffic control devices is over 1,500 feet. It was recommended to use the spacing as recommended by the TxDOT's Sign Crew Field Book (*25*). The treatment was installed in such a configuration at Pecos Test Track due to some physical constraints at the test track.
    - The 400 feet spacing between the advance detector and the red beacons on the Stop was inadequate. The spacing should be equal to the stopping sign distance for the approach speed plus 2 seconds to account for the driver perception reaction time and a lag in the onset of flash in the beacon after the vehicle travels over the advance detector. The treatment was installed in such a configuration at

Pecos Test Track due to some physical constraints at the test track and to facilitate ease of implementation.

- Suggestions to improve the existing treatment:
  - The panel suggested the research team consider development of the treatment that considered the compliance of the approaching vehicle to the Stop sign by monitoring the vehicle speed and activate/escalate the warning if the vehicle was not slowing down at some thresholds.
  - An option to consider was to flash the beacons ONLY if a vehicle was not slowing down.
  - Another flashing beacon configuration to be considered was to have top-bottom and a horizontal beacon arrangement at the Stop sign and have one set of beacons operate normally, but have the other pair of beacons flash if the vehicle was not slowing down.
  - The panel suggested the research team investigate the possibility of dimming the beacons at night to reduce the glare.

FIELD IMPLEMENTATION OF THE TREATMENT

TTI researchers approached the engineers from Odessa District to select an intersection in the district that would meet the criteria. The site required a high speed approach to a stop controlled intersection with a Stop Ahead sign installed on the approach. The Stop sign and the Stop Ahead sign had flashing beacons powered with solar panels.

Site Selected

After a thorough review TxDOT engineers in Odessa District selected the intersection of US 285 and SH 302 in the Odessa District. This intersection is located about 20 miles north of I20 in Pecos, as illustrated in Figure 22.

System Installed

TTI researchers consulted with TxDOT engineers and had a site visit on January 6, 2014. Based on the site visit and availability of TxDOT crew, TTI researchers scheduled the installation of the system at the site on January 22. The TxDOT Odessa District provided three crews to assist in the installation of the system. The Kermit Area office provided traffic control to close off the approaching the intersection. A team from the district office brought the core machine to core the pavement to install the Sensys Sensors. Finally a crew from Signal Shop in Odessa assisted TTI researchers in installing the flasher cabinets and connecting the beacons to the flasher cabinets. Figure 23 illustrates the schematic of the field installation of the system.

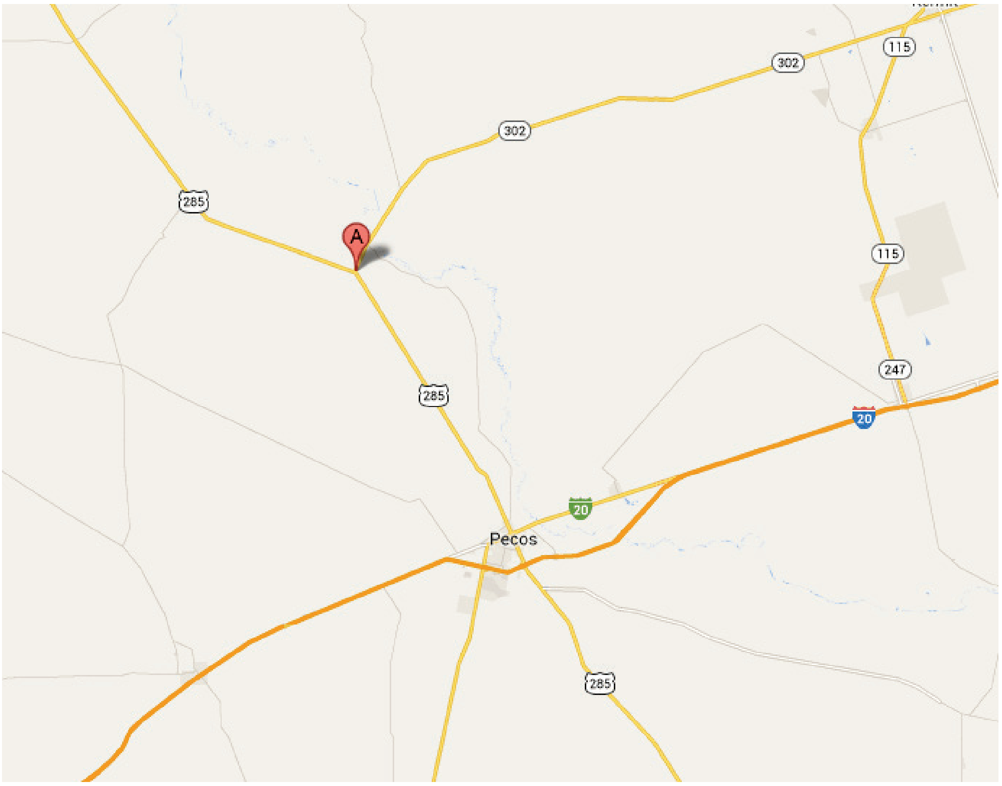

Figure 22. Installation Site near Pecos.

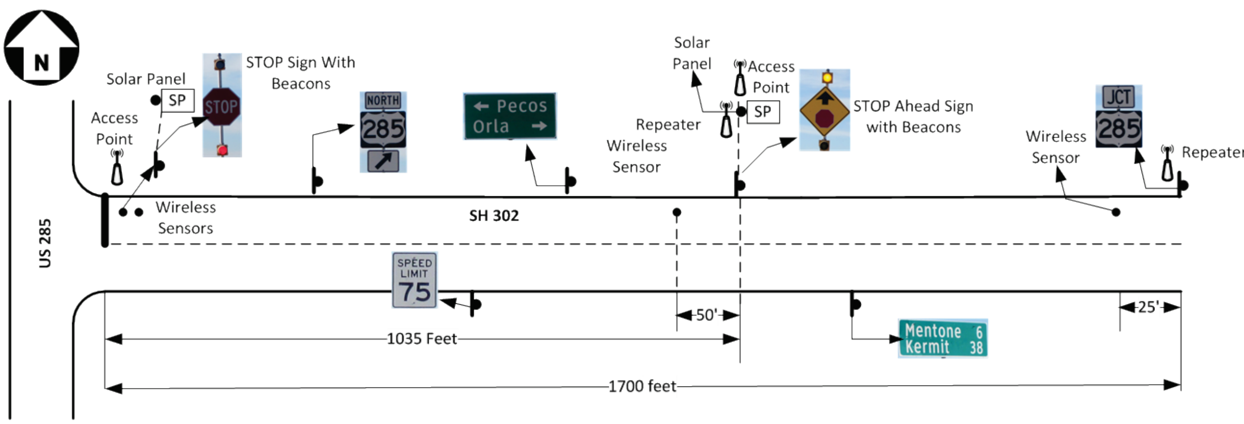

Figure 23. Schematic of the Field Installation.

The system consisted of two sub-systems. The first sub-system consisted of active beacons on a Stop Ahead sign. This sub-system consisted of a wireless sensor (VSN240-F) installed at a distance of approximately 600 feet upstream of the Stop Ahead sign. A long life repeater (RP240-BH-LL) was installed on the back side of the sign post for JCT 28, which was located at a distance of 1700 feet from the Stop Bar. An Access Point (AP240) was installed on the pole on which the solar panel and cabinet with the batteries was installed near the Stop Ahead sign. The flasher cabinet was then installed on the same pole. Figure 24 to Figure 27 illustrate the system being installed.

The second sub-system consisted of active beacons on the stop sign. This sub-system consisted of a wireless sensor (VSN240-F) installed about 50 feet upstream of the Stop Ahead sign and a long life repeater (RP240-BH-LL) installed on the pole with the solar panel near the Stop Ahead sign. The sub-system also had two additional wireless sensors at the Stop Bar (VSN240-T) and an Access Point (AP240) installed on the pole with the solar panel near the Stop sign.

Figure 24. Core Machine Preparing the Pavement to Install the Sensors.

Figure 25. Wireless Sensor Installed in the Core.

Figure 26. Access Point Installation on the Solar Panel Pole.

Figure 27. Flasher Cabinet Installed on the Solar Panel Pole.

PRELIMINARY EVALUATION OF THE INSTALLED SYSTEM

Before the system was installed on January 22, TTI researchers coordinated with the TxDOT engineers from the Odessa District to use their Numetric Counters to collect speed data on the SH 302 approach to US 285. These Numetrics counters can primarily get vehicle speeds and classification and bin them into speed intervals. These counters can typically be left at the site for almost a week. TTI researchers recommended that Numetric counters be installed at 100 feet spacing from 100 feet to 800 feet from the Stop Bars. Figure 28 illustrates the installation of Numetric sensors on the SH 302 approach.

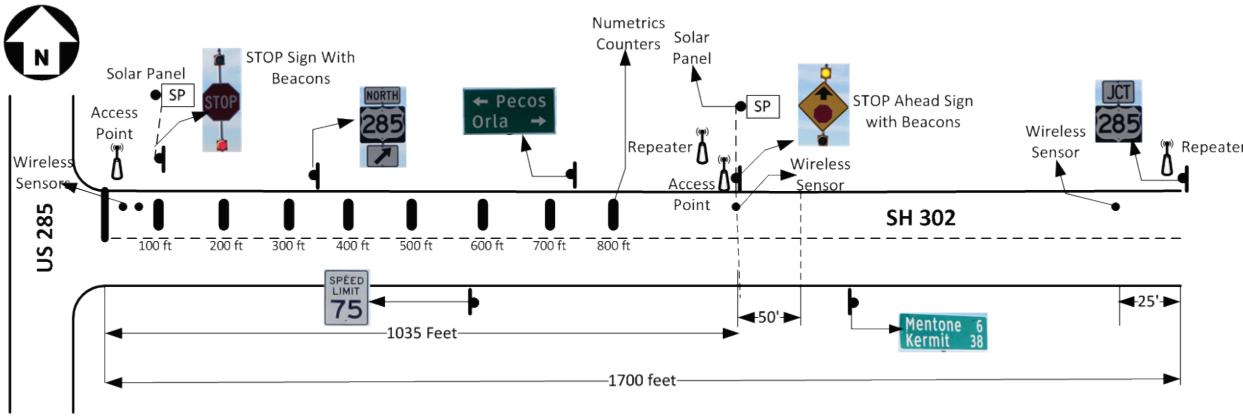

Figure 28. Illustration of the Numetrics Counters Installed to Collect Speed Data on SH 302 Approach.

Before data were collected using Numetric counters from January 16 to January 21, 2014. This data collection effort compared the speed profiles of vehicles before the treatment was installed with the speed profiles after the speed profiles were installed. The hypothesis of this treatment was that the active nature of the devices would slow the motorists when they noticed the beacons starting to flash.

Researchers encountered some challenges after the system was installed. The Stop Ahead sign located at 1035 feet was knocked down during the first week of February. This resulted in the system being down. However, it also was an opportunity to test the failsafe feature that was built into the system as the repeater for the Stop sign was missing from the Stop Ahead sign. When the sign was knocked down, the failure mode kicked in and the beacons on the Stop sign were then flashing continuously as designed.

However, TTI researchers had purchased a spare repeater, which was shipped to the Odessa District after programming it appropriately. Once the repeater was installed by the TxDOT crew on a new Stop Ahead sign assembly, beacons on the Stop sign started functioning as designed.

Figure 29. Stop Ahead Sign Knocked down a Week after Installation of the System.

TTI researchers used the method of mosaic plots to evaluate the impact of any of the deployed systems on driver speeds. The mosaic plot is a method for visualizing frequency data in the contingency tables. A rectangle is recursively divided into rectangular tiles for the cells of the table, such that the area of each tile is proportional to the cell frequency. In these plots, the tiles are divided for each distance and speed bin for the before and after period. The heights of the cells should be approximately equal across the speed bins at each distance level if there are no changes between the before and the after periods. If there are differences, the cells are shaded as dark blue or dark red if the proportion is higher or lower with statistical significance than expected, respectively, in each cell.

Two comparisons were made to assess the effectiveness of the active nature of the Stop signs and Stop Ahead signs.

- **Case 1**: Beacons on both the signs were flashing in an active mode vs. beacons on the Stop sign only in the active mode while the Stop Ahead sign was in a passive mode.
- **Case 2**: Beacons on the Stop sign in the active mode with the Stop Ahead sign in a passive mode vs. beacons on both signs flashing in a passive mode.

A comparison of the two treatments in Case 1 for daytime and nighttime is illustrated in Figure 30 and Figure 31. The following can be inferred from the analysis:

1. During daytime, the approach speeds were less at 400 feet upstream when only the Stop sign was active (speed distribution shifted lower when Stop Ahead sign was passive).
2. Drivers appeared to reduce speed sooner with Stop Ahead always flashing and only the Stop sign was active. This was noticed only during daytime and not during nighttime.

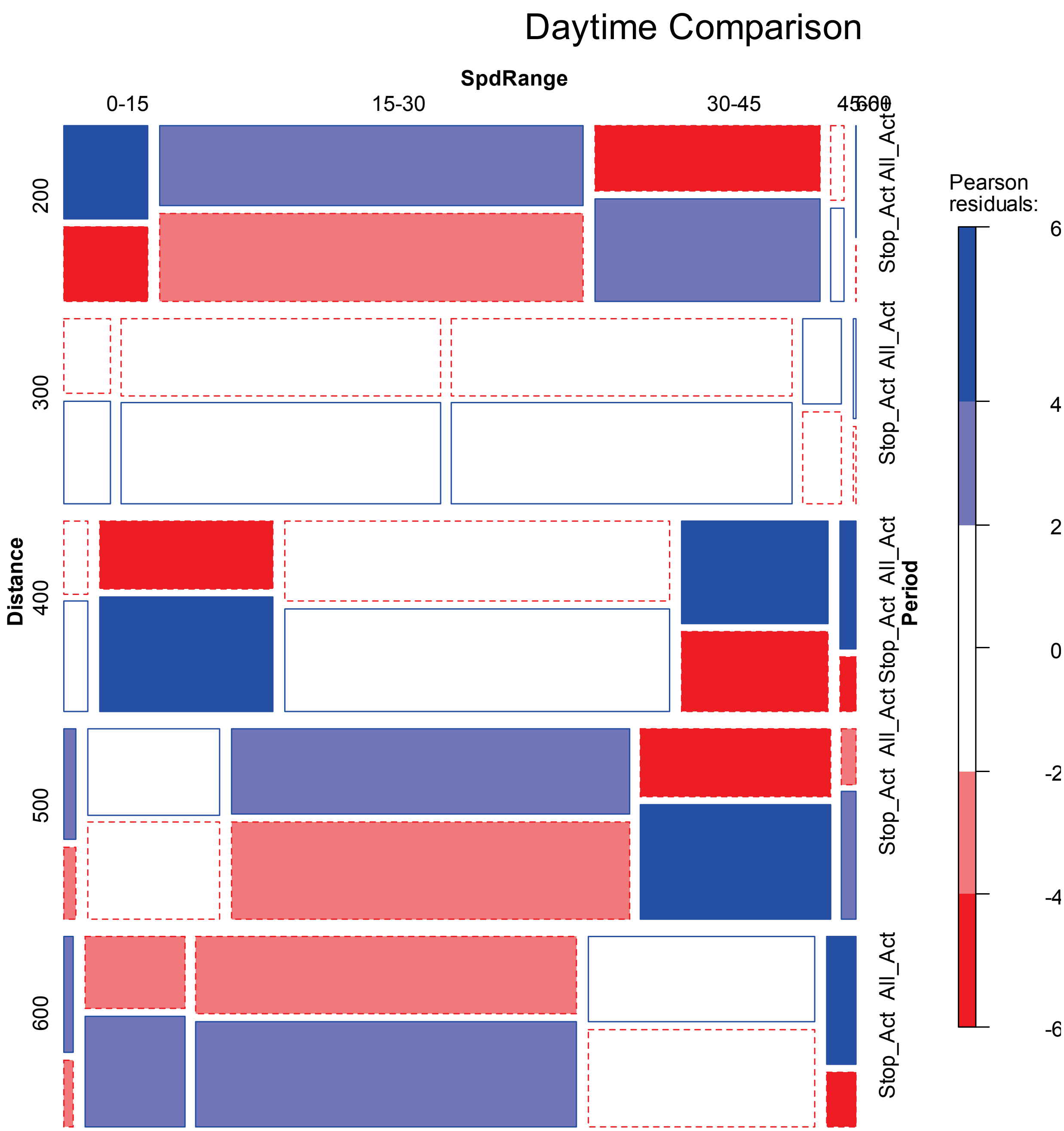

Figure 30. Daytime Analysis of Case 1 Comparison.

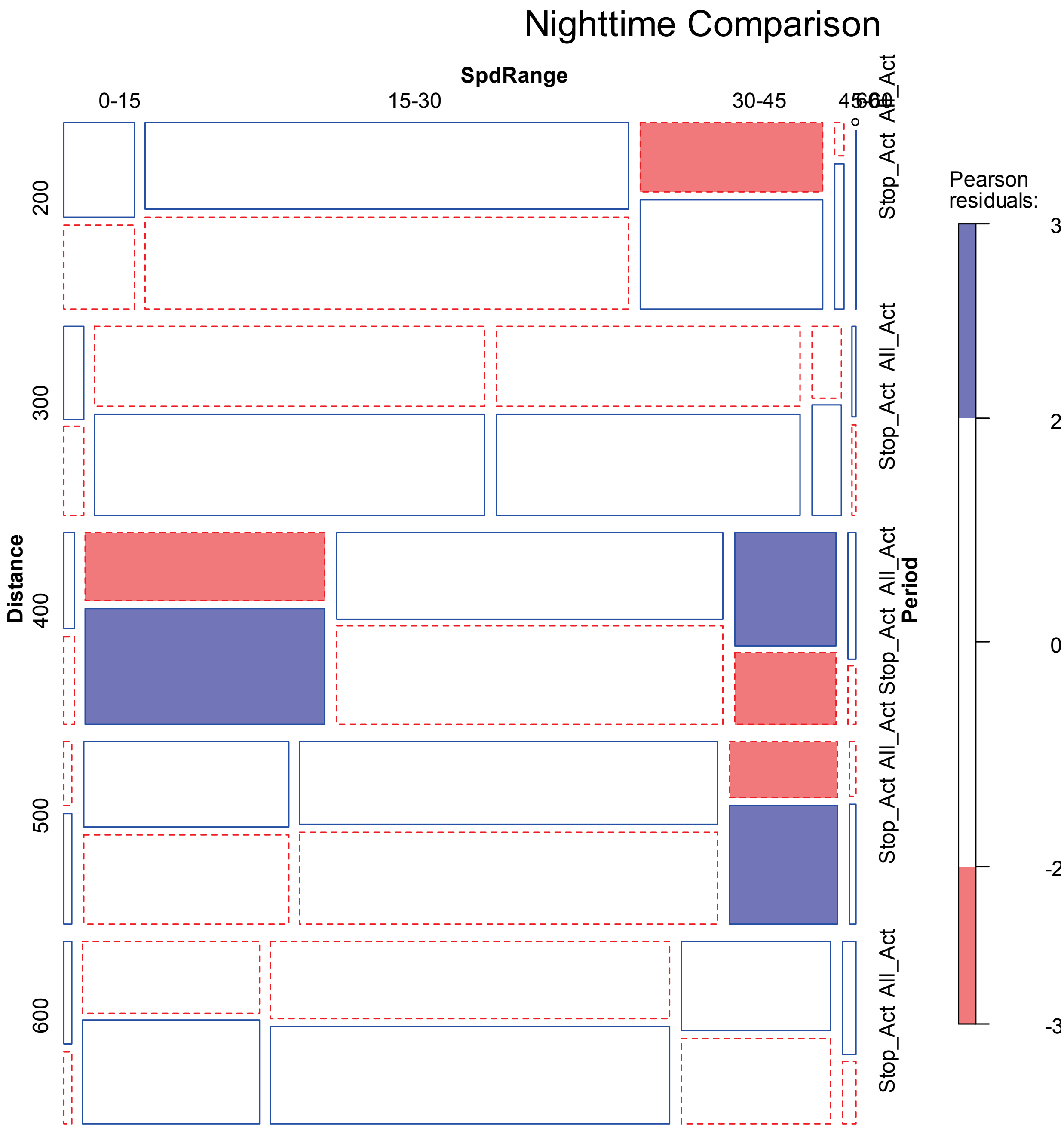

Figure 31. Nighttime Analysis of Case 1 Comparison.

A comparison of the two treatments in Case 2 for daytime and nighttime is illustrated in Figure 32 and Figure 33. The following can be inferred from the analysis:

1. During daytime, more drivers appeared to reduce speed sooner at 400 feet from the Stop sign when only the Stop sign was active (i.e., when Stop Ahead sign was passive).

2. However, the speed reduction does not continue to 300 feet and 200 feet.
3. During nighttime, both setups have very similar impacts on approaching vehicle speeds.

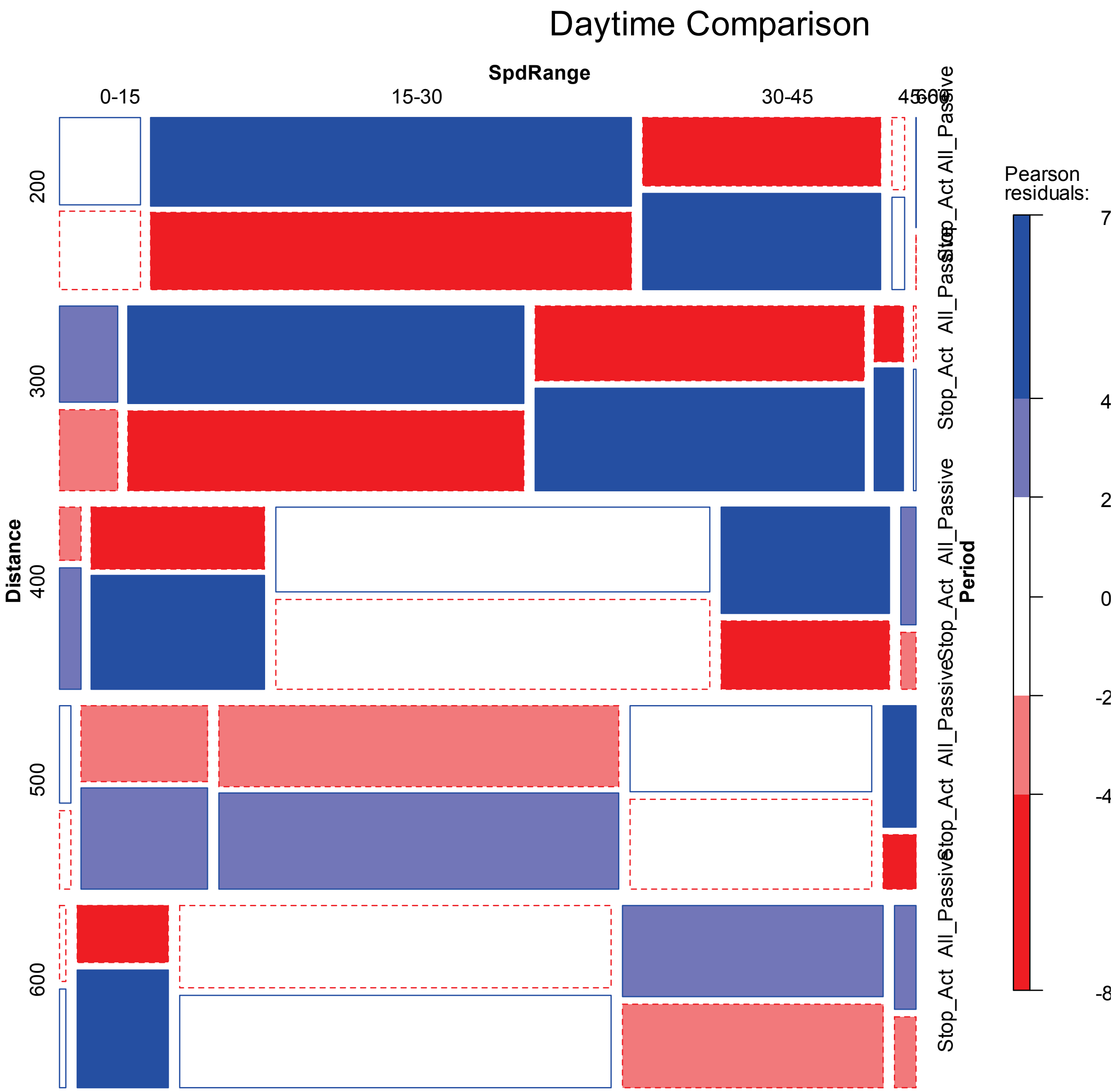

Figure 32. Daytime Analysis of Case 2 Comparison.

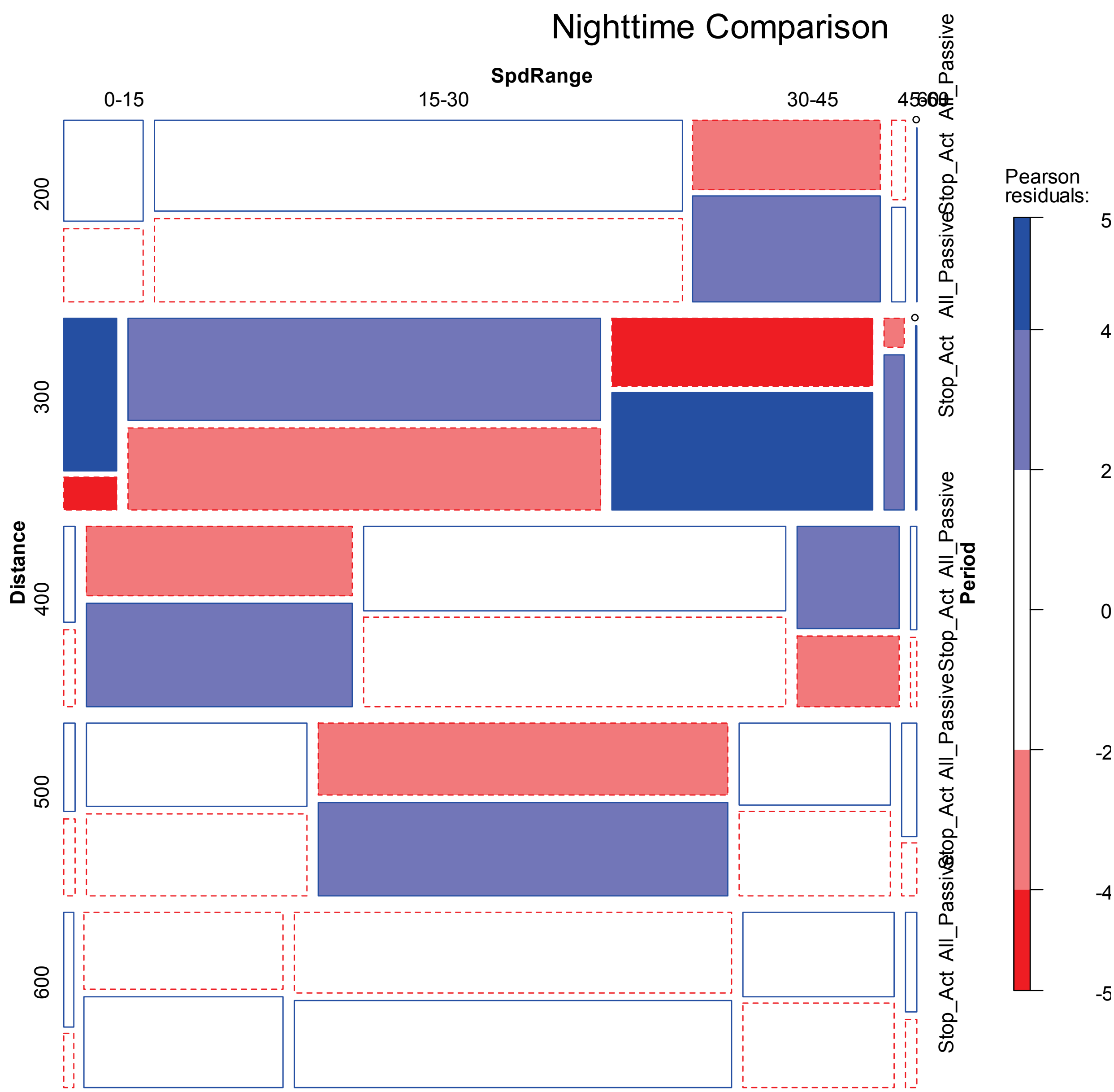

Figure 33. Nighttime Analysis of Case 2 Comparison.

These observations may mean that the beacons on the Stop Ahead sign may be serving their purpose as drivers seemed to slow down farther upstream on the approach to the Stop sign.

DEVELOPMENT OF A NON-COMPLIANT BASED TREATMENT

This section documents the deployment and demonstration of a non-compliant based treatment that will activate the beacons on the Stop sign only when the motorist's speeds exceed the programmed threshold when approaching the Stop sign. As in the earlier deployment, there were two sub-systems. The sub-system for non-compliant system consisted of additional three wireless sensors with an enhanced access point called Access Point Controller Card APCC. These three sensors determined the approach speed of the vehicle and placed a call to the flasher panel if the vehicle speed was greater than a specified value. Once the call was placed, it acted as a trigger to activate the beacons on the Stop sign. The system extended the call to enable the vehicle to reach the Stop Bar. Once the vehicle reached the Stop Bar, the second sub-system was activated. The second sub-system consisted of a detector at the Stop Bar, which was activated by a vehicle. The detector in turn continued to flash the beacons as long as the vehicle was on the detector at the Stop Bar. Once the vehicle left the detection area, the system extended the call for a few seconds to enable the beacons to continue to flash. Such an operation was to prevent frequent terminations and onset of flashing operations.

After consultation with TxDOT engineers, TTI researchers reviewed and selected the intersection of Loop 338 and FM 554 on the outskirts of the City of Odessa to install the treatment on southbound approach of FM 554. This intersection currently has Stop signs with beacons and Stop Ahead signs with beacons.

TTI researchers developed the installation plans for the treatment at the site in Odessa. Figure 34 illustrates the layout of the system at the site. TTI requested TxDOT's assistance to install the four Sensys sensors at locations as illustrated in the figure. The challenge in designing the system was to locate the detectors used to measure speeds. These detectors had to be close enough to the intersection so that vehicles started decelerating to the Stop Bar. However they should be also far away from the intersection to provide enough distance to the motorist to stop if the beacons were activated because the vehicle speed was high. TxDOT also installed a sign post at 500 feet from the Stop Bar to locate the repeater. Finally personnel from Signal Shop assisted in the installation of the repeater on the new sign post, a new APCC radio on the power pole at the Stop Bar, and the flasher panel in the flasher cabinet. TxDOT signal shop technicians also assisted in fine tuning the radios to ensure proper strength of the radio signals from the detectors.

IMPLEMENTATION OF THE SYSTEM

The project implemented a speed based Active Stop sign system. The premise of the system was to activate the beacons on the Stop sign if the speed of the vehicle as detected by the speed sensors was greater than the threshold. In this case for being conservative, it was decided to set the threshold at 30 mph. The objective of the system was to then extend the call for about 10 seconds to ensure that the vehicle reached the Stop Bar sensor before the 10 seconds extension expired. However, during the course of configuring the system, it was discovered that the existing firmware would not allow an extension of greater than 7.5 seconds. Such a configuration frequently resulted in the beacons at the Stop Bar stopping to flash about a second before the vehicle activated the Stop Bar sensor. While this was not the desired implementation, it was found to be acceptable due to firmware and time constraints.

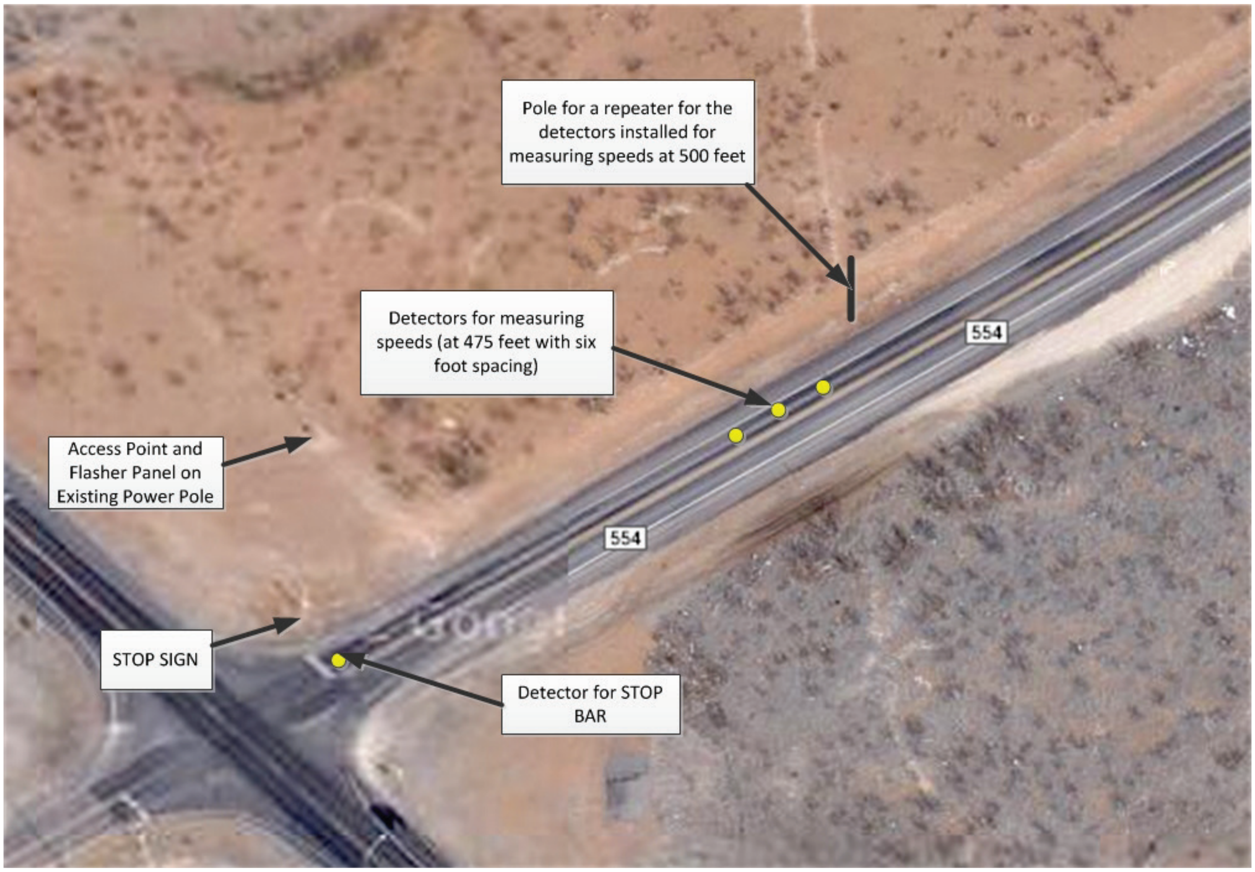

Figure 34. Layout of the System in Odessa.

CONCLUSIONS

This report documented the activities to develop a low cost treatment to improve safety at rural intersections. The objective was to investigate the effectiveness of having the beacons on the Stop sign and Stop Ahead sign operate in an active manner, i.e., to activate the beacons only when a vehicle is approaching the intersection in order to improve the attention value of the Stop sign and Stop Ahead sign. The research team also developed a system to activate the beacons on the Stop sign only when a vehicle exceeds a user defined speed threshold. The following are the conclusions:

1. Speeds tended to be higher when the beacons on the Stop Ahead sign are operating in an active manner. Hence, the team recommended that the beacons on the Stop Ahead sign operate in a passive mode.
2. When the Stop sign was operating in an active mode, speeds at about 400 feet from the Stop sign were lower than when the Stop sign was operating in a passive mode.
3. However this reduction in speeds was not observed at distances closer to the Stop sign.
4. The impact of the active nature of the Stop sign will need to be observed over a longer period of time by observing the safety record of the intersection.
5. TxDOT engineers from the Odessa District observed the operation of the speed based active Stop sign system and had the following observations/concerns:
    a. With the speed threshold being set low enough that most vehicles will trigger the beacons, a question was raised about whom are we not flashing the beacons to and questioned the rationale for that.
    b. There was a strong preference to have the beacons always activated for all vehicles on the approach regardless of vehicle speeds.
    c. A speed based system that could change the flash pattern for a vehicle exceeding the speed threshold was felt to be more appropriate than a system that would just turn the beacons on.
6. Finally, based on the systems installed, tested, and evaluated, it is recommended to further evaluate the active Stop sign system that would activate the beacons for all vehicles approaching the intersection for safety benefits over a longer period of time.

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