Collision Avoidance System

Evaluation Report

January 2007

PENNDOT

Gannett Fleming

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16. Abstract Collision Avoidance Systems (CAS) have been deployed at two locations in the Commonwealth to address limited sight distance concerns at rural unsignalized intersections. By performing evaluations of such projects, we provide the following benefits by answering some basic questions: Document our successes – Has the system provided a realized benefit? Rationalize our investments versus the benefits – Do the financial benefits of the system outweigh the costs? Identify potential improvements – Can the system concept be enhanced by modifying future deployments?		
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How to Use This Document

Symbol	Definition
Blue Underlined Text	Hyperlink. When text is highlighted in this manner, click one time to see additional information about the subject.
	Movie icon. When this is displayed, click the icon one time to see video clips of the subject.
	Camera icon. When this is displayed, click the icon one time to see a collection of photos related to the subject.
	Book icon. When this is displayed, click the icon one time to read more about the subject.
	Projector icon. When this is displayed, click the icon to see a powerpoint presentation on the subject.

1. Executive Summary

1.1. Purpose of Test

Two collision avoidance systems (CAS) were purchased and deployed in Butler County, Pennsylvania in November 2003 to address safety concerns of citizens at unsignalized intersections that have limited sight distance. One deployment is located in the Village of North Washington, North Washington Township at the intersection of SR 38 and North Washington Road (SR 138) and the other in the Village of Hooker, Concord Township at the intersection of SR 38 and Hooker Road (SR 1010). To date there is only one other known installation of similar equipment in Aden, Virginia.

Township/Municipality	SR/ section
North Washington Township	SR 38 at North Washington Road
Concord Township/Village of Hooker	SR 38 at Hooker Road

The Transportation Equity Act for the 21st Century (TEA-21) prescribes that the U.S. Secretary of Transportation issue guidelines and requirements for the evaluation of operational tests and deployment projects for Intelligent Transportation Systems (ITS) for projects under their jurisdiction. The goal of the mandate was to develop a basis for continuing support of decision makers addressing policy and investment issues by providing a clear understanding of ITS system effectiveness.

By performing evaluations of such projects, we provide the following benefits by answering some basic questions:

- ✓ Document our successes – Has the system provided a realized benefit?
- ✓ Rationalize our investments versus the benefits – Do the financial benefits of the system outweigh the costs?
- ✓ Identify potential improvements – Can the system concept be enhanced by modifying future deployments?

Based on the research and stakeholder input and previous studies, the following performance measures and hypotheses were selected for testing:

- ✓ Speed of vehicles traveling on the major road (SR 38)

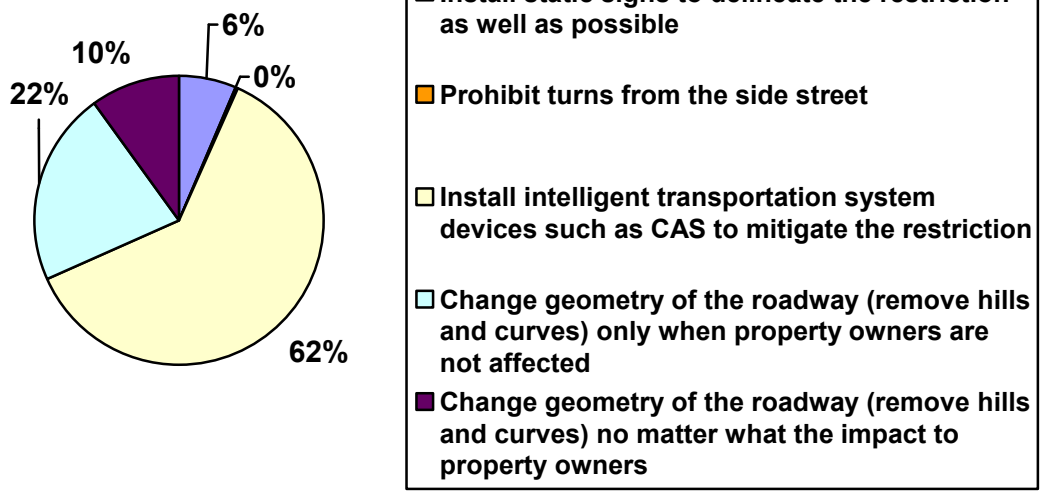
- ✓ Driver behavior
  - Braking reactions on the major road
  - Gap acceptance on the minor roads
- ✓ Crash reduction
  - Number
  - Severity
- ✓ Public perception
- ✓ Stakeholder perception.

1.2. DOCUMENT OUR SUCCESSES

The public survey yielded 224 respondents:

- ✓ 97 percent felt that CAS is beneficial
- ✓ 93 percent felt that CAS should be installed at other locations.

Given the choice on ways to mitigate concerns at an unsignalized rural intersection with poor sight distance, the chart below shows the public prefers CAS.

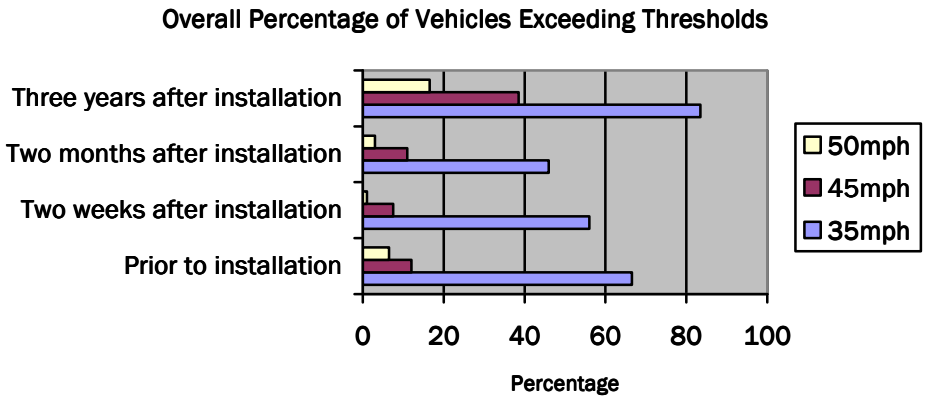


1.2.1. Driver Behavior

To determine driver behavior, SR 38 speeds were recorded in each direction, brake light usage for SR 38 vehicles approaching the intersection were measured and gap acceptance of side street traffic was evaluated.

1.2.1.1. SR 38 Speeds

Speeds were recorded to draw a comparison between speeds prior to the installation of the CAS and current speeds. Overall speeds, speeds with the signs activated and speeds without the signs activated were recorded.



85th, 90th and 95th percentile speeds were an average of 3mph higher with and without the signs activated during the 2006 evaluations than prior to the installation of the CAS.

1.2.1.2. SR 38 Brake Light Usage

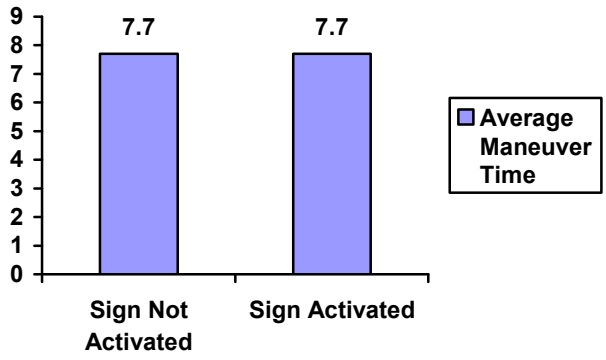
Brake light usage on SR 38 approaching each intersection was recorded for six hours.

- ✓ 28-30 percent of the vehicles approaching the intersection that saw an illuminated sign reacted to the sign by applying their brakes.
- ✓ A higher percentage of vehicles may have used the sign to adjust their travel speed through the area but that percentage could not be determined due to the positive grade approaching each intersection from the north and the south.

While the percentage is not representative of the majority of traffic that traveled the road, it does represent almost 1/3. Given that speeds were exceeding the 35mph posted speed limit prior to installation, this could be viewed as a positive affect.

1.2.1.3. Side Street Gap Acceptance

Side street traffic approaching SR 38 at each intersection encounters limited sight distance when preparing to execute a maneuver. An evaluation of gap acceptance was conducted to see how motorists behave with or without the sign illuminated. The table below shows the maneuver time with and without sign activation. For the sign activation portion, the time spent waiting for an approaching intersection to clear has been removed for an "apples-to-apples" comparison.



Based on the chart above it appears that the signs have not changed driver behavior and the maximum values demonstrate some driver's non-reliance on the system. This analysis was not conducted prior to installing the CAS so a comparison is not possible.

1.2.2. Crash Experience

In the Village of North Washington, there were two angle crashes prior to the CAS and no crashes in the two years of data analyzed after installation.

In the Village of Hooker there was one more crash experienced in the two years after the installation than the two preceding years. In the police report, it was noted that the traffic control device was malfunctioning when one of the crashes occurred.

After analyzing the crash data, it is not conclusive that the CAS was successful in reducing the crashes due to a lack of sample size before and after the installation of the CAS.

1.3. RATIONALIZE OUR INVESTMENTS

Upon initial investigation of these two sites, some may question why traffic signals were not installed. First, traffic signals were not installed

because the neither the side street volumes nor the mainline volumes warranted the installation of a signal. Additionally, the crash experience did not warrant the installation of traffic signals either. Also, each intersection is located at the top of a crest curve, if a signal was installed at either location, stopping/starting of vehicles (particularly trucks) would be a concern as well as the extended limited sight distance at the Hooker intersection.

The two CAS were designed and installed for $422,000. To rationalize this investment, the comparison between installing CAS and geometrically correcting the intersection deficiencies through traditional means should be measured. During field work activities it was determined that to correct the sight distance limitations at these intersections, the vertical curve on SR 38 would need to be lengthened, lowering the elevation of the crest of the curve by twelve feet. This would also require extensive re-grading at each intersection to tie in side streets and slope roadside embankments correctly. The chart below shows a comparison of the two alternatives.

CAS (N. Wash & Hooker)		Intersection Geometry	
ITEM	COST	ITEM	COST
Design	$52,000	North Washington (Including 4 property acquisitions)	$1,094,000
Construction	$370,000	Hooker (including 4 property acquisitions)	$907,000
TOTAL	$422,000	TOTAL	~$2,000,000

As can be seen the estimated construction cost and the cost of acquiring the adjacent properties for correcting the two intersections using traditional means would be almost three times the cost to design and construct the CAS. The 2000 Census indicated that the median selling price for vacant houses in Concord Township was $95,000 and the median selling price for vacant houses in North Washington Township was $47,500. Using the current average inflation rate of 3.43%, the approximate current median property value in these two municipalities is $120,000 and $60,000 respectively.

Not included above, maintenance of the CAS costs $24,000 per year and includes cleaning the system every three months. The maintenance contract is available in the Appendix for review.

1.4. Identify Potential Improvements

Part of the evaluation process is to identify potential improvements. Research, surveys and field activities provided insight into some basic guidance with regard to CAS design and operations.

The following is a summary of basic design considerations:

- ✓ Consider conventional countermeasures first to maximize available resources.
- ✓ Be sure that presence loops are placed out of the path of turning vehicles near the intersection. If vehicles "trip" presence loops from other legs of the intersection when making a turning maneuver it could cause the system to malfunction.
- ✓ Coordination with maintenance forces needs to be emphasized since a malfunctioning loop will compromise the integrity of the system.
    - Video detection may be a viable alternative.
- ✓ Be sure that battery backup systems are kept in good working order.
    - Since a blank sign is displayed when there is no call and also in the case of a power outage, this is especially important.
    - Solar power backup should be evaluated as an option.

1.5. CONCLUSION

The engineering data collected from this evaluation does not present a decisive answer to the question "Is the CAS beneficial", however the public perception of the system indicates that they think it is very beneficial.

From an engineering perspective, the geometric improvements would have potentially offered the greatest increase in safety for motorists; however for these two intersections located in rural Western Pennsylvania, the sociological impacts would have been devastating to these two small villages since the geometric improvements would have required the removal of homes or businesses at both intersections and would likely have destroyed the sense of community that each of these small villages has. The CAS appears to have provided a balance between a perceived increase in safety by users of the intersections and the identity of this area.

The greatest benefit may well have been realized had these two intersections had a high crash history prior to the installation of the CAS, however with a relatively low experience of crashes after the installation of the CAS coupled with the increased volume of traffic, the CAS may have been successful in avoiding an increased crash experience.

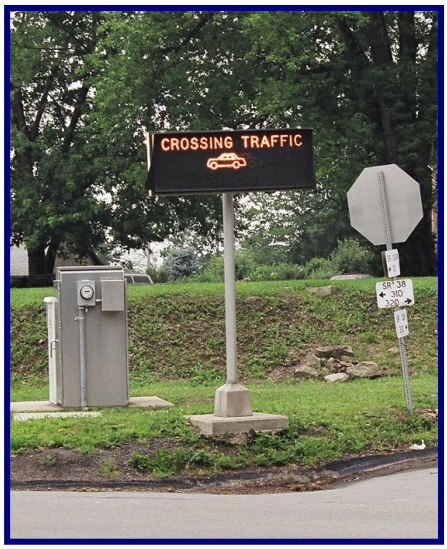
Over 130 minutes of video was collected during this evaluation, click below to review the complete raw video for each site.

2. INTRODUCTION

2.1. PURPOSE OF TEST

Two collision avoidance systems (CAS) were purchased and deployed in Butler County, Pennsylvania in November 2003 to address safety concerns of citizens at unsignalized intersections that have limited sight distance. One deployment is located in the village of North Washington, North Washington Township at the intersection of SR 38 and North Washington Road and the other in the Village of Hooker, Concord Township at the intersection of SR 38 and Hooker Road. To date there has only been one other known installation of similar equipment in Aden, Virginia and that equipment was removed due to disagreements on maintenance responsibilities.

SR 38 Sign with Illuminated Indications



Side Street Sign Indication. This display indicates that a vehicle is approaching from the right.

Township/Municipality	SR/ section
North Washington Township	SR 38 at North Washington Road
Concord Township/Village of Hooker	SR 38 at Hooker Road

2.1.1. Equipment Configuration

Each intersection is configured the same, using inductive loop detectors to transmit a signal to a controller that in-turn transmits a message to activate either the mainline signs or the side street signs. The inductive presence loops located at the intersection are 5 feet wide and 40 feet long except for the southbound approach at Hooker which has a 50 foot long inductive loop. There are also pulse loops installed prior to each SR 38 approach that calculate speeds and identify traffic. Construction drawings, the Operators Manual and the equipment cabinet configuration are available in the Appendix.

2.1.2. Village of North Washington

SR 38 intersects North Washington Road approximately 15 miles north of Butler, PA and 10 miles south of Interstate 80 in Butler County. Each approach to this intersection is a single lane with a posted speed limit of 35mph. Horizontally, SR 38 is in tangent while vertically, the intersection is situated nearly at the crest of a curve with both the north and southbound approaches on a positive five percent grade. A flashing beacon is installed at this intersection.

Approaching the intersection, SR 138 (eastbound approach) has a posted speed limit of 45mph and each approach is relatively flat. Both approaches have limited sight distance of the SR 38 northbound and southbound approaches.

Westbound North Washington Road Looking North	
Westbound North Washington Road Looking South	
Eastbound North Washington Road Looking North	
Eastbound North Washington Road Looking South	

Northbound SR 38 approaching North Washington Road	
Southbound SR 38 approaching North Washington Road	

2.1.3. Test B: Village of Hooker

The intersection of SR 38 and Hooker Road is approximately 4.5 miles south of the Village of North Washington and is located in the Village of Hooker. Each approach to this intersection is a single lane with a posted speed limit of 35mph. Horizontally, SR 38 is in a tangent while vertically, the intersection is situated nearly at the crest of a curve with both the north and southbound approaches on a positive five and three percent grade, respectively. A flashing beacon is installed at this intersection.

Approaching the intersection from the east, Hooker Road has a slight down grade while the west approach to the intersection is flatter but still with a slight down grade.

View of Sight Distance Restriction for Westbound Hooker Road Looking North	
Westbound Hooker Road Looking South	

Eastbound Hooker Road Looking North	
Eastbound Hooker Road Looking South	
Northbound SR 38 approaching Hooker Road	
Southbound SR 38 approaching Hooker Road	

2.2. BACKGROUND

The Transportation Equity Act for the 21st Century (TEA-21) prescribes that the U.S. Secretary of Transportation issue guidelines and requirements for the evaluation of operational tests and deployment projects for Intelligent Transportation Systems (ITS) for projects under their jurisdiction. The goal of the mandate was to develop a basis for continuing support of decision makers addressing policy and investment issues by providing a clear understanding of ITS system effectiveness.

By performing evaluations of such projects, we provide the following benefits by answering some basic questions:

- ✓ Document our successes – Has the system provided a realized benefit?
- ✓ Rationalize our investments versus the benefits – Do the financial benefits of the system outweigh the costs?
- ✓ Identify potential improvements – Can the system concept be enhanced by modifying future deployments?

This evaluation study was developed and conducted consistent with the methodologies presented in the Federal Highway Administration's, *ITS Evaluation Guidelines – ITS Evaluation Resource Guide*.

2.3. PERFORMANCE MEASURES

Based on the research and stakeholder input and previous studies, the following performance measures and hypotheses were selected for testing:

- ✓ Speed of vehicles traveling on the major road (SR 38)
- ✓ Driver behavior
  - Braking reactions on the major road
  - Gap acceptance on the minor roads
- ✓ Crash reduction
  - Number
  - Severity
- ✓ Public perception
- ✓ Stakeholder perception.

2.4. CONTACTS

Agency	Responsibilities
PennDOT District 10-0	✓ Paul Koza, District Traffic Engineer ○ 724-357-2845 ○ pkoza@state.pa.us
Consultant	✓ Mark Metil, Consultant Project Manager ○ 717-763-7212 x2321 ○ mmetil@gfnet.com ✓ Eric Rensel, Traffic Designer ○ 717-763-7212 x2428 ○ erensel@gfnet.com

3. Past Study Reviews

3.1. Aden, Virginia Deployment

A review of two previous studies was conducted to determine possible measures of effectiveness (MOEs) to evaluate the crash avoidance system (CAS) currently deployed at two intersections along SR 38 in Butler County. The first study reviewed was *"Rural Stop-Sign Controlled Intersection Accident Countermeasure System Device Vehicle-Behavioral Evaluation"* published by Transportation Research Corporation, Fred R. Hanscom. This published paper examined the deployment of this system at the intersection of Aden Road and Fleetwood Drive in Aden, Virginia.

3.1.1. Aden, Virginia Study Review

The study evaluated 97,000 vehicles over a 42 day period and focused on 1,652 vehicles that arrived at the intersection in sufficiently close proximity with cross traffic. The study identified six MOEs:

1. Sign Response Speed
2. Intersection Arrival Speed
3. First Speed Reduction
4. Second Speed Reduction
5. Overall Speed Reduction
6. Projected Times to Collision (PTC).

To evaluate MOE one through five, inductive loop detectors were installed at several points approaching the intersections: 950 feet, 410 feet, 350 feet, and at the intersection.

- ✓ Sign Response Speed – inductive loops measured speed 130 feet and 140 feet prior to the posted sign (350 feet and 410 feet prior to the intersection) to measure drivers reactions to the non-activated/activated sign.
- ✓ Intersection Arrival Speed – inductive loops measured speed "within intersection approach".
- ✓ First Speed Reduction – Inductive loop placed 950 feet in advance of the intersection to allow for comparison with other loops.
- ✓ Second Speed Reduction – Inductive loop measured differences between MOE one and two.
- ✓ Overall Speed Reduction – Inductive loop measured differences between MOE two and three.

MOE six was developed from a literature review and represented a theoretical calculated time needed for a motorist to detect, recognize and initiate an appropriate response to an approaching potential crash situation. The study used 3.0 and 4.6 seconds as a sufficient amount

of time for a vehicle to avoid a collision. The 3.0 seconds came from a study by T.R. Neuman, who studied human factors and developed 3.0 seconds as an acceptable perception-reaction time for a primary rural two-lane roadway and the 4.6 seconds comes from a study done by N.H. Lerner evaluating perception reaction time (1.15 second weighted mean), wheel lock-up (0.30 seconds) and skidding to a stop (3.16 seconds). That study assumed an asphalt friction coefficient of .65 and a posted speed of 45 mph.

3.1.2. Aden, Virginia Study Review Conclusion

While speed comprised five of the six identified MOEs, in the end the sixth MOE was the focus of the study and all four conclusion points focused on the reduction in PTC. The conclusion was that the system was effective because PTC times went up and specifically high-speed vehicle groups demonstrated safer PTC times. The study did document the fact that speed reductions realized between the "before" and "acclimation" periods were not sustained between the "before" and "after" periods.

3.2. PENNSYLVANIA DEPLOYMENT

"Rural Stop-Sign Controlled Intersection Crash Avoidance System Device" by Chad A. Mosco, PennDOT 10-0 Tort/Risk Management Coordinator was reviewed to identify previous MOEs for these sites. This study was performed at the subject intersections before, immediately after and two months after installation. The initial configuration was maintained and is discussed in more detail in other sections of this report.

3.2.1. Pennsylvania Deployment 2003 Study Review

The study identified three Evaluations of Effectiveness (EOEs):

- ✓ Vehicle speed responses in the presence of cross traffic
- ✓ Intersection approach speed reductions
- ✓ Crash reduction.

The speed data was evaluated in two different ways:

- ✓ Comparison of vehicles over 50 mph, 45 mph and 35 mph
- ✓ Comparison of 85th, 90th and 95th speeds.

During the "immediately after" and "two months after" periods of the study vehicles were analyzed both while the system was activated and when the system was not activated.

3.2.2. Pennsylvania Deployment 2003 Study Conclusion

The study concluded that the system was of benefit because speeds of approaching traffic on the major roadway (SR 38), speeds of vehicles exceeding 35 mph and 95th percentile speeds went down. The study also noted that speeds through the intersection increased at the time of the two month study while the sign was not illuminated. The study postulated that this phenomenon was a reflection of an increase in the drivers' comfort level with the system.

4. SURVEYS

Another integral component of identifying CAS effectiveness is by gauging user perspectives. A survey of the general public was conducted using an advertised link to the PennDOT 10-0 website and stakeholder interviews were conducted by Gannett Fleming staff. In all, 224 public surveys were received and 14 stakeholder interviews were conducted and analyzed for this study. Results of the survey and stakeholder interviews are presented within this section.

4.1. STAKEHOLDER SURVEYS

During the project kickoff meeting, stakeholders were identified by PennDOT 10-0 staff. Many of the stakeholders were part of the implementation process in 2003 either through public comment or through the design and construction process. Some other stakeholders had considered implementation at other sites.

- ✓ Design and Construction of System Peoples Names
  - McCain Traffic Supply
  - Post Construction
  - Trans Associates, Inc.
  - PennDOT 10-0
  - Pathmaster
- ✓ Considered Installation or Considering Installation
  - New York State Department of Transportation
  - PennDOT 8-0
- ✓ Performed Evaluation
  - Virginia Department of Transportation
  - PennDOT 10-0
- ✓ Local Stakeholders
  - Pennsylvania State Police – Butler Station Troop D
  - Concord Township (Village of Hooker)
  - North Washington Township
  - Moniteau School District
  - Campbell Bus Company (local school bus company)

4.1.1. Stakeholder Survey Results

Each local stakeholder was asked to answer the following survey questions:

- ✓ Does Collision Avoidance Systems provide a benefit to the motorist?
  - PSP – Yes
  - Townships – Yes
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Does the CAS cause you to slow down on SR 38 when the sign in illuminated? – the first time you saw it illuminated?
  - PSP – Yes
  - Townships – Split between yes and no
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Does the CAS cause you to slow down on the SR 38 when the sign is not illuminated? – the first time you saw the sign?
  - PSP – Yes
  - Townships – Split between yes and no
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Does the CAS cause you to use more caution when entering or crossing SR 0038 when the side road sign is illuminated?
  - PSP – Yes
  - Townships – Yes
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Does the CAS cause you to use more caution when entering or crossing SR 0038 when the side road sign in not illuminated?
  - PSP – Yes
  - Townships – Yes
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Does the CAS change your driver behavior on subsequent trips through the area?
  - PSP – Yes
  - Townships – Yes
  - Moniteau School District – Yes
  - Campbell Bus Company - Yes
- ✓ Should the CAS configuration be changed?
  - Warn every vehicle that a dangerous intersection is approaching
    - 2 agreed

- Warn vehicles that are more than 10 mph over the posted speed limit
  - 2 agreed
- Provide additional warning to the side street
  - 1 agreed
  - 1 said that the system is fine
  - 1 said that there was not enough information to answer the question

✓ Is there a location in the Commonwealth where you think a CAS should be installed?
- PSP – Yes
- Townships – No
- Moniteau School District – No
- Campbell Bus Company - No

✓ What other devices do you think would be beneficial to warn drivers approaching traffic?
- No ideas provided

✓ Do you feel that other measures such as flashing beacons, rumble strips, etc are as effective as CAS?
- 1 said that rumble strips could be effective
- All others said no

✓ Given the potential costs below, choose the best option to mitigate sight distance concerns at an intersection
- Install static signs to delineate the restriction as well as possible (up to $2,000) (Option 1)
- Prohibit turns from the side street (up to $5,000) (Option 2)
- Install intelligent transportation system devices such as CAS to mitigate the restriction (up to $400,000) (Option 3)
- Change geometry of the roadway (remove hills and curves) only when property owners are not affected (up to $700,000) (Option 4)
- Change geometry of the roadway (remove hills and curves) no matter what the impact to property owners (up to $2.0 million) (Option 5)
  - PSP selected option 3
  - Townships – Split between option 3 and "not enough information to make a choice"
  - Moniteau School District was neutral
  - Campbell Bus Company was neutral, although they said that the signs do make their drivers more comfortable with the intersections

Stakeholders involved with the design and construction of the two systems did not answer the questions asked above since most have

not traveled through the intersection since the construction was complete. However, all stakeholders in this group felt that the system was beneficial to motorists, below are the key points that stakeholders in the design and construction group made:

- ✓ System software had to be written for the application, this was a significant portion of the design cost
- ✓ Most thought that software development costs should be much lower in the future since only small adjustments will need to be made to fit field conditions
- ✓ Most felt that the CAS was more effective at these two intersections than other measures since geometric changes would severely impact these two small communities.

Stakeholders who have considered installing the CAS also did not answer the stakeholder questions but in interviews with them, they had mixed feelings about the equipment. Below are the key points made by these two stakeholders:

- ✓ The system appears to be a viable alternative to other measures that could be taken to mitigate sight distance concerns at intersections like these two
- ✓ Ultimately our organization was not prepared to take on the liability of the system
- ✓ System malfunctions could affect the public's perception of reliability
- ✓ If the software that was developed can be used for future installations, that would be very beneficial
- ✓ Parties responsible for maintenance costs is a big concern
- ✓ Click here to read an evaluation of CAS for another location within the commonwealth of Pennsylvania

Stakeholders who installed or evaluated CAS equipment thought that the system was very beneficial and could be applicable to other areas. One stakeholder felt that more research needs to be done to study driver behavior for application of this type of system.

4.1.2. Stakeholder Survey Summary

Most stakeholders felt that the two CAS installed in Butler County were beneficial to motorists traveling through the area on SR 38 and each minor approach. During the interview process, the stakeholders were mostly concerned about both the system reliability and motorists' reliability on the system. Many of the stakeholders stressed that they would still like to see periodic speed enforcement on SR 38 to compliment the CAS and nearly all were happy to have the systems installed in lieu of geometric improvements since the necessary

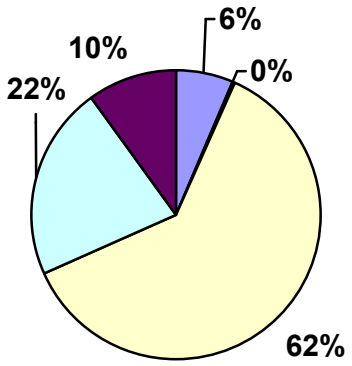
improvements would have displaced many residents of these small villages.

4.2. PUBLIC SURVEYS

The general public was surveyed for this project by advertising a project summary and website link in the Butler Eagle, a daily newspaper published in Butler, Pennsylvania and widely distributed in the project area. The website link was established at the PennDOT 10-0 website. It should be noted that the survey had 224 respondents.

4.2.1. Public Survey Results

- ✓ Does Collision Avoidance Systems (CAS) provide a benefit to you as a driver or motorist?
  - 97 percent answered "yes"
- ✓ Do you understand CAS signs?
  - 99 percent answered "yes"
- ✓ Do you slow down when traveling on SR 38 and the signs are illuminated?
  - 88 percent answered "yes"
- ✓ Do you slow down when traveling on SR 38 and the signs are not illuminated?
  - 81 percent answered "yes"
- ✓ Do you use more caution when entering or crossing SR 38 when the side road sign is illuminated?
  - 91 percent answered "yes"
- ✓ Do you use more caution when entering or crossing SR 38 when the side road sign is not illuminated?
  - 85 percent answered "yes"
- ✓ Do you think that CAS should be installed at other intersections?
  - 93 percent answered "yes"
- ✓ Please circle the best improvement option to mitigate sight distance concerns at an intersection
  - Install static signs to delineate the restriction as well as possible
  - Prohibit turns from the side street
  - Install intelligent transportation system devices such as CAS to mitigate the restriction
  - Change geometry of the roadway (remove hills and curves) only when property owners are not affected
  - Change geometry of the roadway (remove hills and curves) no matter what the impact to property owners



- Install static signs to delineate the restriction as well as possible
- Prohibit turns from the side street
- Install intelligent transportation system devices such as CAS to mitigate the restriction
- Change geometry of the roadway (remove hills and curves) only when property owners are not affected
- Change geometry of the roadway (remove hills and curves) no matter what the impact to property owners

4.2.2. Public Survey Summary

Nearly all of the survey respondents understand the signs and believe that the signs aid them as a motorist. The majority of respondents slow down when approaching the intersection regardless of whether the signs are illuminated or not and 85 percent use more caution when entering from the side road. All respondents agree that CAS should be installed at other intersections within the Commonwealth.

5. Field Observations and Analysis

Field work was conducted on July 12 and 13, 2006 at the two identified locations. Data was collected for both mainline travel (SR 38) and each side street approach (North Washington Road and Hooker Road, respectively).

Township/Municipality	SR/ section	Date of Evaluation
North Washington Township	SR 38 at North Washington Road	July 12
Concord Township/Village of Hooker	SR 38 at Hooker Road	July 13

For each major road approach at each location the following information was collected:

- ✓ Traffic volumes, classification and speed for 14 days
- ✓ Driver behavior at sign activation versus no sign activation for six hours (7-10am and 3-6pm)
  - Brake light usage.

For each minor road approach at each location the following information was collected:

- ✓ Traffic volumes, classifications and speed for 14 days
- ✓ Gap acceptance for six hours (7-10am and 3-6pm)
- ✓ Gap/delay with no sign activity
- ✓ The amount of time for a vehicle to arrive from the Major Road when the sign is illuminated
- ✓ The time to accept the gap with sign activity.

Four staff members were used to evaluate each site and each staff member had the same assignment for each location to increase consistency with data collected. Additionally, sample video was captured at each approach for reference.

Subsequent speed data was collected on October 30, 2006 and November 1, 2006 to evaluate the speed of vehicles with the sign activated versus not activated for vehicles traveling on SR 38.

5.1. DATA ANALYSIS

5.1.1. Test Traffic Volumes and Speeds

Traffic volumes, vehicle classifications and vehicle speeds were recorded for fourteen days in July. The below charts and graphs summarize the observed information. At the time of the field work, the east leg of Hooker Road had just been chipped, therefore collection of that leg was delayed. See the Appendix for the raw count data.

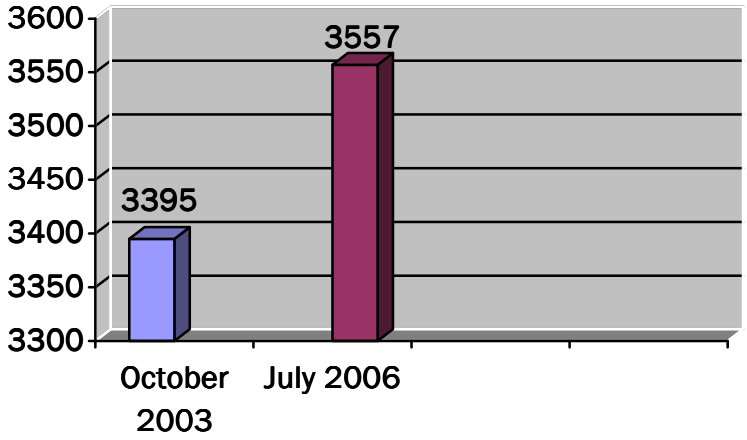
Location and Direction	Date	Daily Traffic Total	Number of Vehicles Class 4 and Above	Heavy Vehicle Percentage	Average Daily Traffic	Average Truck Percentage
SR 38, North Washington NB	12-Jul-06	1687	175	10.4	1767	9.9
	13-Jul-06	1855	178	9.6		
	14-Jul-06	2129	181	8.5		
	15-Jul-06	1793	109	6.1		
	16-Jul-06	1286	57	4.4		
	17-Jul-06	1645	157	9.5		
	18-Jul-06	1697	169	10		
	19-Jul-06	1699	190	11.2		
	20-Jul-06	1802	177	9.8		
	21-Jul-06	2124	199	9.4		
	22-Jul-06	1603	85	5.3		
	23-Jul-06	1292	47	3.6		
	24-Jul-06	1603	165	10.3		
	11-Jul-06 and 25-July-06	1433	149	10.4		

Location and Direction	Date	Daily Traffic Total	Number of Vehicles Class 4 and Above	Heavy Vehicle Percentage	Average Daily Traffic	Average Truck Percentage
SR 38, North Washington SB	12-Jul-06	1974	227	11.5	1970	10.7
	13-Jul-06	2095	214	10.2		
	14-Jul-06	2104	216	10.3		
	15-Jul-06	1955	101	5.2		
	16-Jul-06	2118	112	5.3		
	17-Jul-06	2003	205	10.2		
	18-Jul-06	1908	213	11.2		
	19-Jul-06	2033	235	11.6		
	20-Jul-06	2007	208	10.4		
	21-Jul-06	2093	227	10.8		
	22-Jul-06	1770	102	5.8		
	23-Jul-06	2107	109	5.2		
	24-Jul-06	1951	211	10.8		
	11-Jul-06 and 25-July-06	1534	157	10.2		
SR 38, Hooker NB	26-Jul	1976	178	9	2094	9.2
	27-Jul	2068	207	10		
	28-Jul	2537	202	8		
	29-Jul	2108	93	4.4		
	30-Jul	1089	46	4.2		
	31-Jul	1912	176	9.2		
	25-Jul-06 and 1-Aug-06	1977	189	9.6		
SR 38, Hooker SB	12-Jul-06	2061	250	12.1	2013	10.8
	13-Jul-06	2125	226	10.6		
	14-Jul-06	2181	222	10.2		
	15-Jul-06	1964	108	5.5		
	16-Jul-06	2031	103	5.1		
	17-Jul-06	2071	222	10.7		
	18-Jul-06	2012	225	11.2		
	19-Jul-06	2024	244	12.1		
	20-Jul-06	2033	225	11.1		
	21-Jul-06	2124	251	11.8		
	22-Jul-06	1802	95	5.3		
	23-Jul-06	2059	113	5.5		
	24-Jul-06	1998	218	10.9		
	11-Jul-06 and 25-July-06	1500	111	7.4		

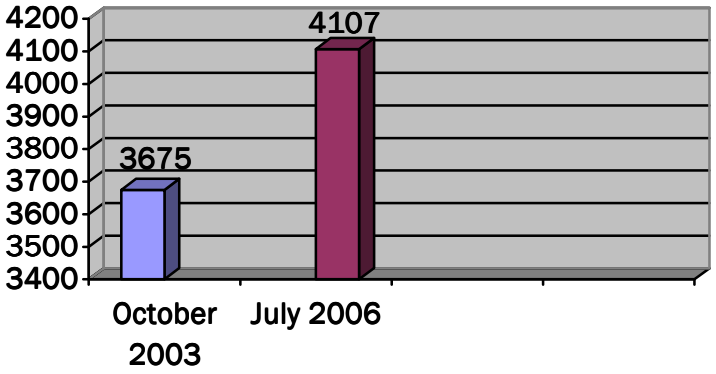
Saturday or Sunday, not included

Below is a comparison with the PennDOT 2003 Report: *Rural Stop-Sign Controlled Intersection Crash Avoidance System Device.*

Village of North Washington: Average Entering Daily Traffic



Village of Hooker: Average Entering Daily Traffic



One of the key measures of effectiveness that was identified in the PennDOT 2003 Report: *Rural Stop-Sign Controlled Intersection Crash Avoidance System Device* was the speed of vehicles approaching the intersection on SR 38. In that report, the speed of vehicles was chronicled in two ways: the percentage of vehicles exceeding 35mph (Speed limit), 45mph and 50mph; and, the 85th, 90th and 95th percentile speeds when the sign was activated versus not activated.

Subsequent speed data was collected on October 30, 2006 and November 1, 2006 at each intersection to study what affect the signs had on speed when they were activated.

- ✓ SR 38 at North Washington Road
  - 50 vehicles observed with SR 38 signs not activated
    - 74 percent exceeded the posted speed limit (35mph)

- 38 percent exceeded 40mph
- 16 percent exceeded 45mph
- None exceeded 50mph

- 50 vehicles observed with SR 38 signs activated
  - 66 percent exceeded the posted speed limit (35 mph)
  - 34 percent exceeded 40mph
  - 18 percent exceeded 45mph
  - 1 vehicle exceeded 50mph

✓ SR 38 at Hooker Road

- 100 vehicles observed with SR 38 signs not activated
  - 79 percent exceeded the posted speed limit (35mph)
  - 50 percent exceeded 40mph
  - 26 percent exceeded 45mph
  - 9 vehicles exceeded 50mph
- 100 vehicles observed with SR 38 signs not activated
  - 79 percent exceeded the posted speed limit (35mph)
  - 31 percent exceeded 40mph
  - 12 percent exceeded 45mph
  - 5 vehicles exceeded 50mph

Below is Table 1 from the *"Rural Stop-Sign Controlled Intersection Crash Avoidance System Device"* with data collected in July 2006 added.

Location	Speed Threshold	Percentage Exceeding Threshold			
		Prior	Two-week	Two-month	July 2006
North Washington	35 mph	66	50	34	92
	45 mph	17	9	4	57
	50 mph	9	0	1	28
Hooker	35 mph	67	62	58	75
	45 mph	7	6	18	20
	50 mph	4	2	5	5

The values for the July 2006 percentages were determined by averaging the northbound and southbound percentages for each location. In all cases except the 50mph threshold for Test B the percentages of vehicles exceeding the identified threshold increased.

Below is a comparison of speeds for the **activated signs**:

Location	Percentage Speed	Vehicle Speeds		
		Prior	Two-month	October/November 2006
North Washington	85	42	37	47
	90	44	39	48
	95	48	44	49
Hooker	85	47	41	45
	90	49	43	46
	95	51	48	50

As can be seen from the table above, speed data collected three years after the installation of the system indicates that speeds are equal to or near speeds recorded prior to the installation of the two systems.

Below is a comparison of speeds for signs **not activated**:

Location	Percentage Speed	Vehicle Speeds		
		Prior	Two-month	October/November 2006
North Washington	85	42	46	46
	90	44	47	47
	95	48	49	49
Hooker	85	47	42	49
	90	49	44	50
	95	51	46	55

From the two tables shown above, speeds on SR 38 at North Washington Road have increased since the CAS has been installed. At Hooker Road, speeds have remained relatively flat since CAS has been installed. The results of this analysis support the public surveys in which 81 to 88 percent of respondents said that they use more caution approaching the intersection.

5.1.2. Driver Behavior at Sign Activation vs. No Sign Activation

Driver behavior was observed for six hours at each approach to each intersection to gage reaction to the posted signs. As described in the beginning of this section, drivers on the main street are warned of vehicles preparing to enter the roadway by an illuminated W2-1 and supplemental TRAFFIC AHEAD illuminated indication. Additionally, traffic on the side street is warned of approaching traffic by an illuminated sign indicating from which direction vehicles are approaching.

5.1.3. Brake Light Usage

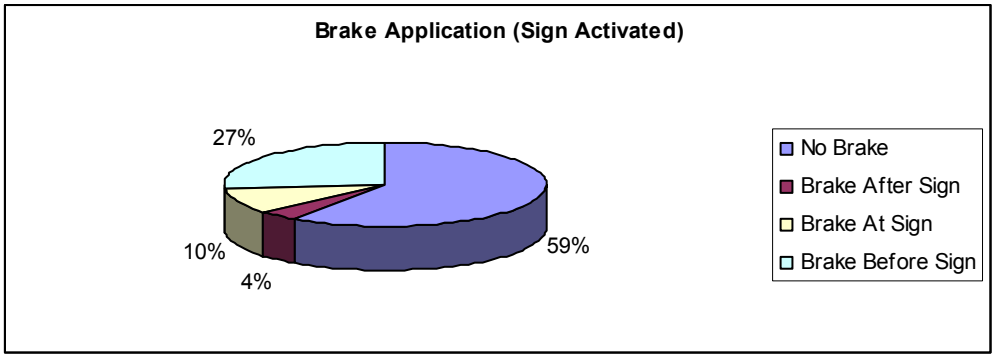
Brake lights were counted as they were applied on the north/south bound approaches of SR 38 at the two study intersections. Observers recorded four different types of brake light applications during two scenarios; CAS sign illuminated or not illuminated on SR 38. The four different types of brake light applications are as follows:

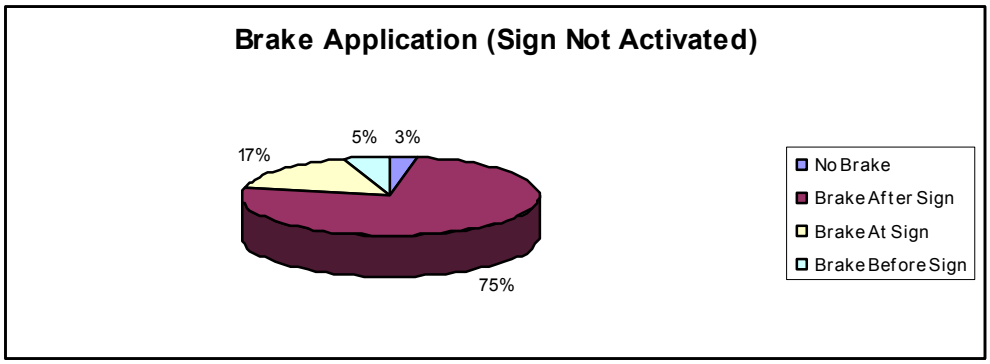
- ✓ No braking
- ✓ Braking before the first CAS sign
- ✓ Braking at the CAS sign
- ✓ Braking after the CAS sign.

Braking before the first CAS sign was determined to be 300 feet. This distance was established based on 6 inch lettering on the CAS signs and the basis that a driver can read 1 inch of text 50 feet away.

Most motorists applied their brakes when following too closely or at the intersection because the vehicle in front of them was turning. This may seem misleading but the crest curves must be taken into consideration. The average grade on approaches of both intersections is at least 3%. Once the sign was activated, it appeared in the field that those motorists were using the crest curves to slow down instead of applying their brakes. When the sign was not illuminated the traffic appeared to flow steadily through the intersections. *The Brake Application (Not Illuminated) Chart* shows a high number of "Brake After Sign", but these motorists were applying their brakes because they were tailgating or turning into the adjacent side streets.

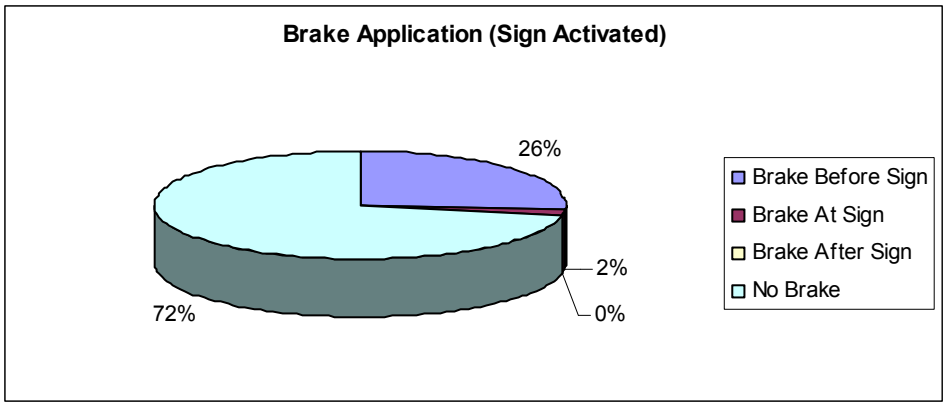
North Washington Intersection

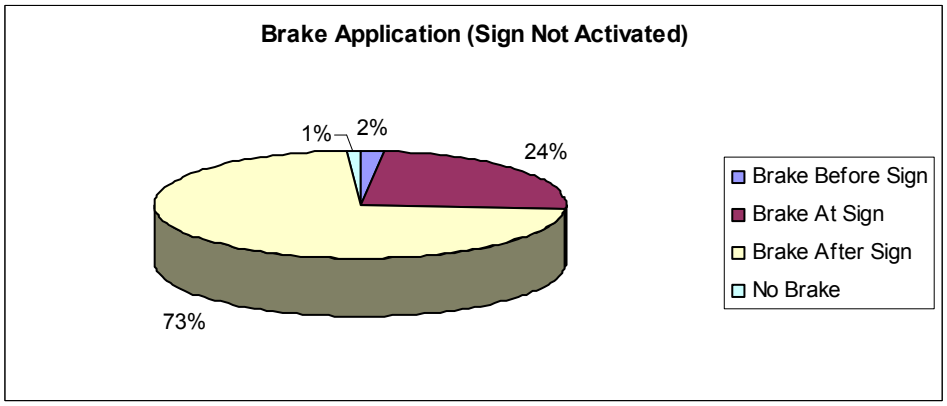




Note: 80-90% of "Brake After Sign" were due to tailgating or motorists turning into side streets.

Hooker Intersection





Note: 80-90% of "Brake After Sign" applications were due to tailgating or motorists turning into side streets.

Based on the charts shown above, 28-30% of drivers react to the illuminates signs by applying their brakes.

5.1.4. Side Street Gap Acceptance

Gap acceptance was chosen as a measure of driver reaction for vehicles entering SR 38 from the side street. The data collected consisted of three items:

- ✓ Time to complete maneuver from the side street when the sign is not illuminated
- ✓ Time to complete the maneuver from the side street when the sign is illuminated
- ✓ Time for an SR 38 vehicle to arrive at the intersection after the sign is illuminated.

209 maneuvers were observed from side street approaches to SR 38 and the following charts outline the results of the observations.

Statistical Value	Sign Activated			Sign Not Activated		
	Left	Thru	Right	Left	Thru	Right
n	32	32	14	28	50	47
Average	18.8	19.2	18.1	8.4	7.3	7.4
Sample Median	14.5	14	16.5	8	7	6
Sample Standard Deviation	15.7	15.6	8.7	3.2	3.2	6.9
Confidence (95th)	5.4	5.4	4.6	1.2	0.9	2
Min	13.4	13.8	13.5	7.2	6.4	5.4
Max	24.2	24.6	22.7	9.6	8.2	9.4

The chart above compares times for sign activations versus non-sign activation times. When the sign was not activated, the maneuver times were relatively constant regardless of the direction the maneuver was being made with a small deviation, yielding maneuver times of 5.4 to 9.6 seconds based on the 95th percent confidence interval. When the sign was activated, maneuver times went up considerably as did the standard deviation. To correctly compare the maneuver times of sign activations versus non-sign activations, the time a side street vehicle spends waiting for an approaching vehicle to clear the intersection must be removed. 184 observations of the time for a vehicle to arrive were recorded.

Time for vehicle to Arrive	
n	184
Average (seconds)	11
Median	11
Standard Deviation	2.3
Confidence (95th)	0.3
Min	10.7
Max	11.3

The time for vehicles to arrive was consistent for this sample with a range of 10.7 to 11.3 seconds. Removing these values from the sign activation observations above gives the following comparison.

Maneuver Time	Sign Activation			Sign Non-Activation		
	Left	Thru	Right	Left	Thru	Right
Min	5.6	5.6	6.4	7.2	6.4	5.4
Max	16.4	16.4	15.6	9.6	8.2	9.4
Average	7.8	8.2	7.1	8.4	7.3	7.4

The results show that towards the minimum, vehicles will turn left and straight faster when the sign is activated and only one second slower to turn right. This indicates that drivers trust the technology and proceed when the sign is no longer illuminated. Towards the maximum of the range, the results indicate that drivers will take considerably more time to make the maneuver. This indicates that some drivers do not trust the technology and wait to make the maneuver until they feel it is safe. A comparison of the average values indicates that the maneuver times are similar. These comparisons indicate that it is difficult to find a pattern in maneuver time whether or not the signs are activated, however, given the fact that the average times are close and that the lower threshold values are slightly less for the activated condition, it is likely that motorists are relying on the system somewhat in their decision making process.

5.1.5. Crash History Review

A review of the crash history at these intersections was conducted to determine if the CAS was successful in:

- ✓ Reducing the Amount of Crashes and/or
- ✓ Reducing the Severity of Crashes.

Crash data was supplied by PennDOT 10-0 for two years prior to installation and two years after construction. Below is a summary of crash data at each location.

Village of North Washington				
Time Period	Driver Action Leading to Crash	Crash Location	Crash Type	Crash Severity
Before ITS 4/1/1999 - 12/31/2000	Proceeded w/o clearance	Intersection	Angle	Minor Injury
	Proceeded w/o clearance	Intersection	Angle	Major Injury
After ITS 4/1/2004 - 12/31/2005	No Crashes at the intersection			

Village of Hooker				
Time Period	Driver Action Leading to Crash	Crash Location	Crash Type	Crash Severity
Before ITS 4/1/1999 - 12/31/2000	Failure to respond to TCD	Intersection	Angle	Property Damage Only
	Over/Under compensate curve	Mid-Block	Hit Fixed Object	Minor Injury
After ITS 4/1/2004 - 12/31/2005	Running red light	Intersection	Angle	Minor Injury
	Improper/careless turn	Intersection	Opposite Direction Sideswipe	Property Damage Only
	Too fast for conditions	Mid-Block	Hit Fixed Object	Minor Injury

In the Village of Hooker there was one more crash experienced in the two years after the installation than the two preceding years.

After analyzing the crash data, it is not conclusive that the CAS was successful in reducing the crashes due to a lack of sample size before and after the installation of the CAS.

6. FINDINGS

As described in Section 2.2, TEA-21 prescribes that the U.S. Secretary of Transportation issue guidelines and requirements for the evaluation of operational tests and deployment projects for Intelligent Transportation Systems (ITS) for projects under their jurisdiction. The goal of the mandate was to develop a basis for continuing support of decision makers addressing policy and investment issues by providing a clear understanding of ITS system effectiveness.

By performing evaluations of such projects, we provide the following benefits by answering some basic questions:

- ✓ Document our successes – Has the system provided a realized benefit?
- ✓ Rationalize our investments versus the benefits – Do the financial benefits of the system outweigh the costs?
- ✓ Identify potential improvements – Can the system concept be enhanced by modifying future deployments?

6.1. DOCUMENT OUR SUCCESSES

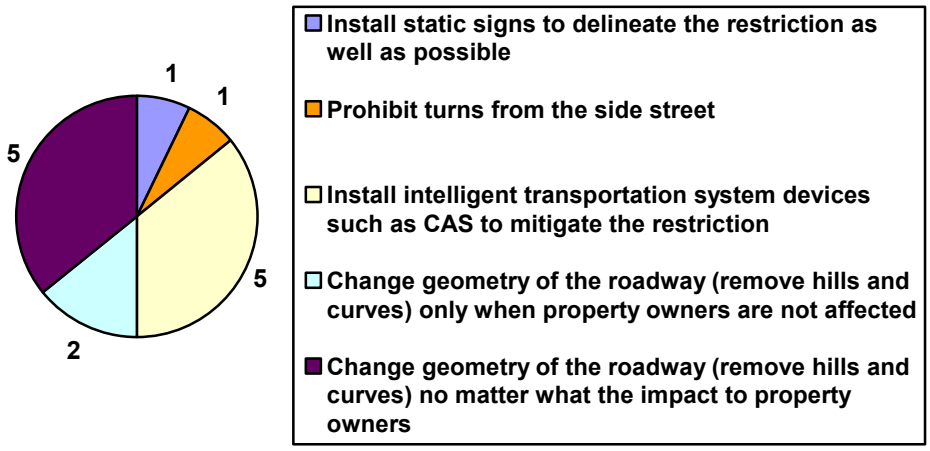
This evaluation identified public and stakeholder input, SR 38 speeds, side street gap acceptance and crash history as measures of effectiveness in determining if the collision avoidance systems installed in Butler County, PA are a success.

6.1.1. Public and Stakeholder Input

The public survey had 224 respondents:

- ✓ 97 percent felt that CAS is beneficial
- ✓ 93 percent felt that CAS should be installed at other locations.

Given the choice on ways to mitigate concerns at an unsignalized rural intersection with poor sight distance, the chart below shows the public response.



Most stakeholders felt that the two CAS installed in Butler County were beneficial to motorists traveling through the area on SR 38 and each minor approach. During the interview process, the stakeholders were mostly concerned about both the system reliability and motorists' reliability on the system. Many of the stakeholders stressed that they would still like to see periodic speed enforcement on SR 38 to compliment the CAS and nearly all were happy to have the systems installed in lieu of geometric improvements since the necessary improvements would have displaced many residents of these small villages.

6.1.2. Driver Behavior

To determine driver behavior, SR 38 speeds were recorded in each direction, brake light usage for SR 38 vehicles approaching the intersection were measured and gap acceptance of side street traffic was evaluated.

6.1.2.1. SR 38 Speeds

Speeds were recorded for fourteen days and the following information was obtained.

Location	Speed Threshold	Percentage Exceeding Threshold			
		Prior	Two-week	Two-month	July 2006
North Washington	35 mph	66	50	34	92
	45 mph	17	9	4	57
	50 mph	9	0	1	28
Hooker	35 mph	67	62	58	75
	45 mph	7	6	18	20
	50 mph	4	2	5	5

Speeds measured in July 2006 were the highest recorded of any other study time period. One explanation of this fact may be that in examining the average daily traffic, northbound and southbound volumes are fairly consistent from day-to-day and directional split. This may point towards system reliance.

In October 2006, speeds were evaluated with the signs activated and without the signs activated. In both cases, speeds were relatively equal with speeds measured prior to system deployment.

In addition the percentage of vehicles exceeding 50mph increased after installation but has not increased in the three years since the study that was conducted two-months after installation.

6.1.2.2. SR 38 Brake Light Usage

Brake light usage on SR 38 approaching each intersection was recorded for six hours.

- ✓ 28-30 percent of the vehicles approaching the intersection that saw an illuminated sign reacted to the sign by applying their brakes.
- ✓ A higher percentage of vehicles may have used the sign to adjust their travel speed through the area but that percentage could not be determined due to the positive grade approaching each intersection from the north and the south.

While the percentage is not representative of the majority of traffic that traveled the road, it does represent almost 1/3. Given that speeds were exceeding the 35mph posted speed limit prior to installation, this could be viewed as a positive affect.

6.1.2.3. Side Street Gap Acceptance

Side street traffic approaching SR 38 at each intersection encounters limited sight distance when preparing to execute a maneuver. An evaluation of gap acceptance was conducted to see how motorists behave with or without the sign illuminated. The table below shows the maneuver time with and without signs activated. For the sign activation portion, the time spent waiting for an approaching intersection to clear has been removed for an "apples-to-apples" comparison.

Maneuver Time	Sign Activated			Sign Not Activated		
	Left	Thru	Right	Left	Thru	Right
Min	5.6	5.6	6.4	7.2	6.4	5.4
Max	16.4	16.4	15.6	9.6	8.2	9.4
Average	7.8	8.2	7.1	8.4	7.3	7.4

Using statistical analysis and looking at the minimum and average values, the signs do not appear to have drastically changed driver behavior and the maximum values demonstrate some driver's non-reliance on the system.

6.1.3. Crash Experience

Crash data was supplied by PennDOT 10-0 for two years prior to installation and two years after construction. Below is a summary of crash data at each location.

Village of North Washington				
Time Period	Driver Action Leading to Crash	Crash Location	Crash Type	Crash Severity
Before ITS 4/1/1999 - 12/31/2000	Proceeded w/o clearance	Intersection	Angle	Minor Injury
	Proceeded w/o clearance	Intersection	Angle	Major Injury
After ITS 4/1/2004 - 12/31/2005	No Crashes at the intersection			

Village of Hooker				
Time Period	Driver Action Leading to Crash	Crash Location	Crash Type	Crash Severity
Before ITS 4/1/1999 - 12/31/2000	Failure to respond to TCD	Intersection	Angle	Property Damage Only
	Over/Under compensate curve	Mid-Block	Hit Fixed Object	Minor Injury
After ITS 4/1/2004 - 12/31/2005	Running red light	Intersection	Angle	Minor Injury
	Improper/careless turn	Intersection	Opposite Direction Sideswipe	Property Damage Only
	Too fast for conditions	Mid-Block	Hit Fixed Object	Minor Injury

In the Village of Hooker there was one more crash experienced in the two years after the installation than the two preceding years. In the police report for the angle crash, it was noted that the traffic control device was malfunctioning.

After analyzing the crash data, it is not conclusive that the CAS was successful in reducing the crashes due to a lack of sample size before and after the installation of the CAS.

6.2. RATIONALIZE THE INVESTMENT

Upon initial investigation of these two sites, some may question why traffic signals were not installed. First, traffic signals were not installed because the neither the side street volumes nor the mainline volumes warranted the installation of a signal. Additionally, the crash experience did not warrant the installation of traffic signals either. Also, each intersection is located at the top of a crest curve, if a signal was installed at either location, stopping/starting of vehicles (particularly trucks) would be a concern as well as the extended limited sight distance at the Hooker intersection.

The two CAS were designed and installed for $422,000. To rationalize this investment, the comparison between installing CAS and geometrically correcting the intersection deficiencies through traditional means should be measured. During field work activities it was determined that to correct the sight distance limitations at these intersections, the vertical curve on SR 38 would need to be lengthened, lowering the elevation of the crest of the curve by twelve feet. This would also require extensive re-grading at each intersection to tie in side streets and slope roadside embankments correctly. The chart below shows a comparison of the two alternatives.

CAS (N. Wash & Hooker)		Intersection Geometry	
ITEM	COST	ITEM	COST
Design	$52,000	North Washington (Including 4 property acquisitions)	$1,094,000
Construction	$370,000	Hooker (including 4 property acquisitions)	$907,000
TOTAL	$422,000	TOTAL	~$2,000,000

As can be seen the estimated construction cost and the cost of acquiring the adjacent properties for correcting the two intersections using traditional means would be almost three times the cost to design and construct the CAS. The 2000 Census indicated that the median selling price for vacant houses in Concord Township was $95,000 and the median selling price for vacant houses in North Washington Township was $47,500. Using the current average inflation rate of 3.43%, the approximate current median property value in these two municipalities is $120,000 and $60,000 respectively.

Not included above, maintenance of the CAS costs $24,000 per year and includes cleaning the system every three months. The maintenance contract is available in the Appendix for review.

6.3. FUTURE ENHANCEMENTS

Part of the evaluation process is to identify potential improvements. Research, surveys and field activities provided insight into some basic guidance with regard to CAS design and operations.

The following is a summary of basic design considerations:

- ✓ Consider conventional countermeasures first to maximize available resources.
- ✓ Be sure that presence loops are placed out of the path of turning vehicles near the intersection. If vehicles "trip" presence loops from other legs of the intersection when making a turning maneuver it could cause the system to malfunction.
- ✓ Coordination with maintenance forces needs to be emphasized since a malfunctioning loop will compromise the integrity of the system.
    - Video detection may be a viable alternative.
- ✓ Be sure that battery backup systems are kept in good working order.
    - Since a blank sign is displayed when there is no call and also in the case of a power outage, this is especially important.
    - Solar power backup should be evaluated as an option.