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FINAL REPORT

EVALUATION OF INTERSECTION COUNTERMEASURES ON HIGH-SPEED RURAL MULTI-LANE FACILITIES

Georgia Department of Transportation

OFFICE OF MATERIALS AND RESEARCH
RESEARCH AND DEVELOPMENT BRANCH

GDOT Research Project 07-19

Final Report

EVALUATION OF INTERSECTION COUNTERMEASURES ON HIGH-SPEED RURAL MULTI-LANE FACILITIES

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16. Abstract:

The primary objective of this study is the evaluation of the effectiveness of several proposed safety treatments at two intersections in Habersham County, Georgia. The intersections selected for this study had high crash rates leading to a Georgia Department of Transportation proposal for various safety improvements. To evaluate the impact of the safety treatments, this study focused on an evaluation of various surrogate measures of safety: speed, acceleration/deceleration rate, and Post Encroachment Time (PET). The study used video recording as the primary data collection methodology and used custom software, developed as a part of the project, for data reduction of the resulting videos. GPS probe vehicles were used to provide a ground truth reference. Data collected showed that the treatment had negligible impact on the behavior of the vehicles studied regarding the surrogate measures considered.

As a follow up study, the use of PET data as a surrogate measure was further explored. The objective of this investigation was to determine the utility of using PET to rapidly determine the potential safety impact of a treatment. For this investigation data were collected at two pairs of intersections. Each pair was selected to be of similar geometry and volumes but of different crash rates. For the given intersections PET demonstrated the potential to distinguish between highly significant safety differences although it remains uncertain what magnitude of safety difference may be identified. Additional research will be needed before PET can be viewed as a robust quantitative surrogate measure for estimating intersection safety.

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EXECUTIVE SUMMARY

The primary objective of this study is the evaluation of the effectiveness of several proposed safety treatments at two intersections in Habersham County, Georgia. The intersections selected for this study had high crash rates leading to a Georgia Department of Transportation proposal for various safety improvements. To evaluate the impact of the safety treatments, this study focused on an evaluation of various surrogate measures of safety: speed, acceleration/deceleration rate, and Post Encroachment Time (PET). The study used video recording as the primary data collection methodology and used custom software, developed as a part of the project, for data reduction of the resulting videos. GPS probe vehicles were used to provide a ground truth reference. Data collected showed that the treatment had negligible impact on the behavior of the vehicles studied regarding the surrogate measures considered.

As a follow up study, the use of PET data as a surrogate measure was further explored. The objective of this investigation was to determine the utility of using PET to rapidly determine the potential safety impact of a treatment. For this investigation data were collected at two pairs of intersections. Each pair was selected to be of similar geometry and volumes but of different crash rates. For the given intersections PET demonstrated the potential to distinguish between highly significant safety differences although it remains uncertain what magnitude of safety difference may be identified. Additional research will be needed before PET can be viewed as a robust quantitative surrogate measure for estimating intersection safety.

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INTRODUCTION

The primary objective of this study is the evaluation of the effectiveness of several proposed safety treatments at two intersections in Habersham County, Georgia. The intersections selected for this study had high crash rates leading to a Georgia Department of Transportation proposal for various safety improvements.

Traditionally, crash data would be used for the safety analysis of the proposed treatments. However, while crash data allows for the direct evaluation of the safety of a facility, it has limitations in terms of both time and accuracy. Accidents are rare events and thus a long time frame (typically on the order of 3 years) is required to allow for evaluation of results with a meaningful level of confidence. In addition, crash data are often inaccurate and/or incomplete due to limitations of the local and state police reports from which they are derived. Finally, analysis of crash data provides little or no insight into the pre-crash process. In other words, crash data alone does not provide sufficient information on the behavior of the vehicles before they were involved in the crash.

To address the need for short- and mid-term assessment of the proposed mitigation measures, surrogate measures of safety were evaluated. The use of surrogate safety measures allows for faster safety analysis in comparison to crash data. Surrogate measures are also considered in situations where historical crash data are limited or not available.

For the Habersham County study, the effectiveness of several proposed safety treatments at the intersection of US23/SR 365 & CR387 (Demorest Mt. Airy Hwy) were evaluated. As an initial step, a traditional analysis of crash data for a period of 3 years before the application of safety treatment was performed to help identify the critical conflict(s) that were to be addressed in the later project stages.

To evaluate the impact of the safety treatments, the study focused on evaluation of three surrogate measures of safety: speed, acceleration/deceleration rate, and post encroachment time. The study used video recording as the primary data collection methodology and used custom software, developed as a part of the project, for data reduction of the resulting videos. To validate the data collection methodology and to find the optimal smoothing algorithm (to reduce noise inherent in the data reduction process), GPS probe vehicles were used to provide a ground truth reference. Data collected showed that the treatment had negligible impact on the behavior of through vehicles (in the presence of a left turn vehicle and no approach queue) regarding any of the surrogate measures considered. The first portion of this report discusses the Habersham county intersection study in detail.

As a follow up to the Habersham study, the use of Post Encroachment Time (PET) data as a surrogate measure is further explored in the second portion of this report. The objective of this investigation was to determine the utility of using PET to rapidly determine the potential safety impact of a treatment in a before/after analysis or as a ranking tool of safety differences between intersections. For this investigation data were collected at two pairs of intersections. Each of the pairs was selected to be of similar geometry and volumes but of very different crash rates.

The first pair of intersections were located along SR10 at Grayson Parkway and at Henry Clower Blvd/Oak Road. As in the Habersham study, data collection focused on the conflict of through vehicles versus the opposing left turn. For these intersections, there was not a significant difference in the PET distributions in the critical range (sub three second) even though the ten year crash frequencies differed by a factor of approximately six (11:63).

For the second pair of intersections, the criteria that the intersections be along the same corridor was relaxed and intersections with higher differences in crash frequencies were selected. The high accident intersection selected was Wieuca Road with Roswell Road in the City of Atlanta (123 crashes between through and opposing left turn vehicles between 2000 and 2009) while the low accident intersection was Buford Highway with Sugarloaf Parkway in Gwinnett County (7 crashes over the same period). In this case, the higher accident intersection showed significantly more critical (sub three second) PET values than did the low accident intersection. This ratio (about 3.3 times), while substantial, was significantly less than the nearly twenty fold difference in crash frequencies. Thus, while for the given intersections, PET has demonstrated the potential to distinguish between highly significant safety differences, it remains uncertain what level of safety difference may be identified. Additional research will be needed before PET can be viewed as a robust quantitative surrogate measure for estimating intersection safety.

The reminder of this report presents the Habersham County study and Post Encroachment Time study in detail.

THE HABERSHAM COUNTY STUDY

Summary of Results

The objective of this portion of the study was to evaluate the effectiveness of several proposed safety treatments at the intersections of US23/SR 365 & CR387 (Demorest Mt. Airy Hwy) in Habersham County and US23/SR 365 & CR395 (Crane Mill Rd) also in Habersham County. The two intersections selected for this study had high observed rates of crashes and fatalities leading to a Georgia Department of Transportation proposal for various safety improvements. As an initial step in evaluating these improvements, a traditional analysis of crash data for a period of 3 years before the application of the safety treatments was performed to help identify the critical conflict(s) that were to be addressed in the later project stages. This analysis indicated that, as expected, the critical conflict at this intersection was between left turning vehicles and opposing through vehicles on the mainline.

To evaluate the impact of the safety treatments, the study focused on an evaluation of various surrogate measures of safety that were available throughout the project time frame. The study used video recording as the primary data collection methodology and used custom software, developed as a part of the project, for data reduction of the resulting videos. To validate the data collection methodology and to find the optimal smoothing algorithm (to reduce noise inherent in the data reduction process), GPS probe vehicles were used to provide a ground truth reference. Data collected at the intersection of US23/SR 365 & CR387 (Demorest Mt. Airy Hwy) showed that the treatment had negligible impact on the behavior of through vehicles (in the presence of a left turn vehicle and no approach queue) regarding any of the surrogate measures considered for either the northbound or southbound approaches. Based on these results, data collection was eliminated for the Crane Mill Road site and the resources were devoted to the PET study.

Introduction

Traditionally, crash data has been used for transportation safety analysis. Crash data allows for the direct evaluation of the safety of a facility but has severe limitations in terms of both time and accuracy. Accidents are rare events and thus a long time frame (typically on the order of 3 years) is required to allow for evaluation of results with a meaningful level of confidence. In addition, crash data are often inaccurate and/or incomplete due to limitations of the local and state police reports from which they are derived. Finally, analysis of crash data provides little or no insight into the pre-crash process. In other words, crash data alone does not provide sufficient information on the behavior of the vehicles before they were involved in the crash.

To address the need for short- and mid-term assessment of the proposed mitigation measures, surrogate measures of safety were evaluated. The use of surrogate safety measures allows for faster safety analysis in comparison to crash data. Surrogate measures are also considered in situations where historical crash data are limited or not available. According to the white paper by Tarko et al. (Tarko, et al. 2008), a surrogate measure of safety can be defined as “A measurable or observable non-crash event that is physically related in a predictable and reliable way to crashes and can be converted or calibrated into crash frequency and/or severity."

Figure 1 presents a conceptual relationship between surrogate measures and safety. The horizontal arrow depicts the causal relationship between surrogate measures of safety and crashes and indicates that the surrogate event must occur for the corresponding crash to happen. The effect of a safety treatment on a surrogate measure of safety is depicted by the leftmost vertical arrow. This arrow indicates that if a treatment affects safety, the treatment should also affect a surrogate event. Safety may also be affected by factors which cannot be reflected by surrogate measures, as indicated by the rightmost vertical arrow. The more powerful the surrogate measure, the better it will capture the effect of the treatment.

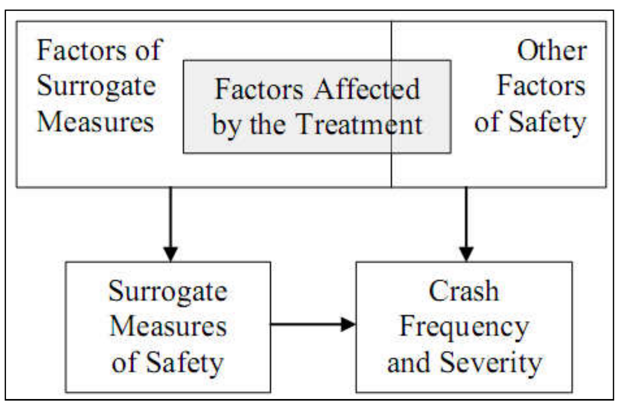


Figure 1 Relationship between crashes and surrogate measures of safety (Tarko, et al. 2008)

Several potential surrogate measures may be determined through conflict analysis which consists of observing the interactions between multiple vehicles and quantifying the number of near-misses, evasive actions taken (e.g. braking or weaving), and erratic maneuvers. For example, one study at urban intersections has shown a ratio of conflicts to crashes of about 2000:1 (Older and Spicer 1976). Thus, changes in the number of observed conflicts can give an early indication of the effectiveness of mitigation measures. The types of conflicts observed may also aid in selection of additional measures focused on addressing the high conflict areas. So, conflicts (or surrogate measures) may allow for an early estimate of the impact of the safety treatment thus avoiding the need to wait for accidents to occur in evaluating the effect of a safety treatment. Surrogate measures also may be used to aid in determining contributing factors to crash types as they focus on pre-collision and avoidance behaviors.

To complement the traditional approach of analyzing crash data to evaluate safety treatments, this study included the evaluation of various surrogate measures that were available throughout the project time frame. Specifically, this research focused on evaluating proposed safety treatments at two high-speed rural intersections having high observed rates of crashes and fatalities.

Background

As mentioned previously, the use of surrogate safety measures allows for an earlier safety analysis in comparison to crash data. The *traffic conflict technique* is one such surrogate measure and to date much of the available literature focuses on the use of traffic conflicts as a surrogate safety measure (Perkins and Harris 1967) (Sayed and Zein 1999) (Parker and Zegeer 1989) (Hyden 1987). Unfortunately, this approach allows for some level of subjectivity as the detection of a conflict requires human interpretation of maneuvers and a subjective decision as to whether a particular maneuver qualifies as a conflict. The various surrogate safety measures used in previous studies or mentioned in the literature are:

- *Braking or Maneuvering* (Perkins and Harris 1967).
- *Gap Time* - Time interval between completion of encroachment by a turning vehicle and the arrival time of a crossing vehicle if they continue with same speed and path (Songchitruksa and Tarko 2004).
- *Post Encroachment Time (PET)* - Time interval between the end of encroachment of turning vehicle and the time at which the through vehicle actually arrives at the potential point of collision (Songchitruksa and Tarko 2004).
- *Deceleration Rate* - Rate at which a crossing vehicle must decelerate to avoid a collision (Gettman and Head 2003).
- *Encroachment Time* - Time duration during which the turning vehicle infringes upon the right-of-way of the through vehicle (Gettman and Head 2003).
- *Initially attempted PET* - Time interval between the commencement of encroachment by a turning vehicle plus the expected time for the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle (Gettman and Head 2003).
- *Proportion of stopping distance* - Ratio of distance available to maneuver to the distance remaining to the projected location of collision (Gettman and Head 2003).
- *Critical events*, e.g., aggressive lane merging, speeding, and running on red (Porter, Berry and Harlow 1999) (Shoarian-Sattari and Powell 1987)
- *Acceleration Noise* (Shoarian-Sattari and Powell 1987)

- *Extended Time-To-Collision (TTC)*– Length of time a TTC event remains below threshold (Minderhoud and Bovy 2001).
- *Time-Integrated TTC*– Integral of the TTC-profile during the time it is below threshold (Minderhoud and Bovy 2001).

There are a few drawbacks for some of the measures used in previous studies. For example:

- Shoarian-Sattari and Powell considered acceleration noise and the mean velocity gradient as safety indicators. They used an on-board servo-accelerometer mounted horizontally and aligned in the longitudinal direction of the motion to collect field data, however they collected only eight profiles owing to the difficulty in measurement (Shoarian-Sattari and Powell 1987).
- Braking and maneuvering are some evasive actions taken by the drivers to avoid a collision and can be detected in the field. But detection requires human recognition and judgment that is an inherently subjective process. Automated post processing of video recordings has the potential to reduce the variation due to human interpretation and subjectivity to some extent but this technology has not been fully developed.
- Surrogate measures such as speed profiles, deceleration rates, time-integrated-Time-To-Collision (TTC) have not been extensively considered largely due to the difficulty of field measurement and the data intensity of these measures.

- Minderhoud and Bovy proposed time-exposed TTC and time-integrated TTC and tried to extract them using microscopic simulation models (Minderhoud and Bovy 2001). The potential to derive various surrogate measures of safety from existing simulation models has also been investigated in a FHWA study (Gettman and Head 2003). But any simulation approach assumes that the model is representative of the actual field conditions which may or may not be correct since the accuracy of results from simulation models depend on the accuracy of the model in replicating the actual behavior of the vehicles.
- While measures like TTC, PET (Post Encroachment Time), and Gap Time help in determining the probability of collisions (or frequency of collisions); they do not represent the severity of collisions as severity depends on speed which the above measures do not consider (Gettman and Head 2003). So, a measure like deceleration rate takes into account both speed and time and therefore may help in determining both the possibility and severity of crashes.

Profile based approaches can also be considered. Recent advancements in video and image processing technology have paved the way for automated detection of vehicles and their motion (Kanhere, et al. 2006) (Chin, Quek and Cheu 1992). Research is also being done on using computer vision technology in determining various traffic parameters (Beymer, et al. 1997) (Vasquez and Fraichard 2004) and in developing a vision-based system to issue warnings about imminent collisions in real-time (Atev, et al. 2005) (Maurin, Masoud and Papanikolopoulos 2005). A review of the literature shows that imaging technology has also been used in detection of conflicts (Saunier and Sayed 2007) for a few surrogate measures such as Post Encroachment Time (PET) and Gap Time (Songchitruksa and Tarko 2004). The literature also suggests the use of automatic vehicle detection methods for calculating speeds of vehicles by using a larger detection zone. However, such methods have not been validated with results (Kanhere, et al. 2006). The paper by Kanhere, et al. also concludes that further research needs to be done for handling intersections and cases which involve multiple cameras (Kanhere, et al. 2006).

There are additional hurdles associated with a completely automated detection methodology. These include occlusion, vehicle and headlight reflections, false calls, etc. Though recent research has tried to overcome these hurdles, limitations still exist in terms of camera interface requirements and associated equipment investments. Resource limitations in studies such as the one reported in this effort allow the camera to have a much lower angles to the horizon (5^0) to cover a larger area with less equipment. Such low angles are often incompatible with automated vehicle profile detection methodologies. For example, the Next Generation Simulation (NGSIM) software from Cambridge Systematics, Inc extracts vehicle positions from video obtained from multiple cameras and translates it into vehicle tracking data. However, these approaches have limitations in terms of the camera interface requirements such as resolution, camera angle, bit rate, etc., which limit their usage in this type of research.

To meet the need of collecting profile based surrogate measures in this study, custom software was developed for efficiently reducing the video recordings using a combination of automatic and manual interactions. Post-processing and analysis of the video recording produces the time and position data for each vehicle. The speed and acceleration/deceleration profiles of the vehicles may then be calculated from the developed time-space profiles.

Research Approach

The first stage of the project involved conducting a literature review and preparing summaries of the study intersections (intersections of US23/SR 365 & CR387 (Demorest Mt. Airy Hwy) and US23/SR 365 & CR395 (Crane Mill Rd)). The literature review concentrated on the methods used for intersection safety evaluation with focus on surrogate measures. The results of this literature review have been presented in the previous section (Background) of this report.

In preparation for the later field studies, an operational and geometric analysis of the study intersections was conducted. Field conditions including intersection geometry, traffic control parameters, volume and speed data, and sight distance were collected. Available crash data for the two intersections were also reviewed and collision diagrams were prepared. Based on these collision diagrams and consultations with GDOT personnel, the opposing left-turn conflict was identified as the critical conflict for study. Based on this determination, the surrogate measures to be collected were selected. These were: 1) the acceleration/deceleration profile of the through vehicle, 2) the speed of the through vehicle and 3) the Post Encroachment Time (PET) for the conflict.

The primary method selected to collect the conflict analysis data was video recording as it allowed for a permanent record of the intersection operations and obtaining the conflict data from these recordings in laboratory environment rather than in the field. A detailed description of the data collection methodology is presented in Data Collection and Processing.

Data were collected at the first primary intersection (US23/SR 365 & CR387 (Demorest Mt. Airy Hwy)) using video recording and analysis of the video data was accomplished using custom developed software (discussed in Data Reduction Software). This first data collection period (13th of August, 2008 to 25th of September, 2008) was in advance of the installation of the additional safety treatments at the intersection. After application of the treatments at the intersection by GDOT personnel, video data was again collected and was reduced to obtain post installation conflict data. The effect of the treatment on the safety of the intersection was evaluated by comparing the before and after treatment conflict data. The analysis of these conflict data in the form of surrogate measures and the results are discussed in Results and Findings of the Habersham Study.

Data Collection and Processing

Measurement Sites

As mentioned earlier, the study area consisted of two high speed intersections in north Georgia (US23/SR 365 and Demorest Mt. Airy Highway (CR387) in Habersham County, Georgia and US23/SR 365 & CR395 (Crane Mill Rd) also in Habersham County, Georgia). The study area is indicated in Figure 2 below.

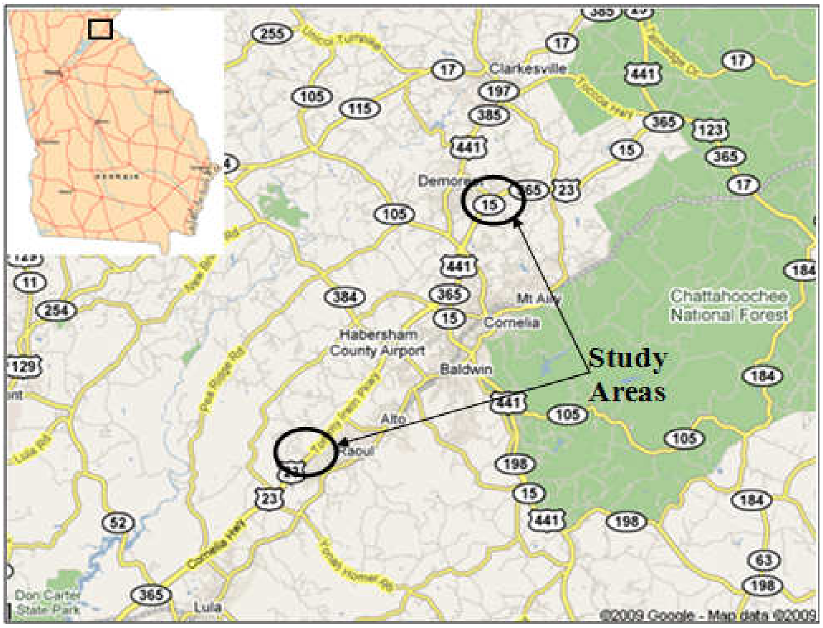


Figure 2 Map showing locations of the two study intersections with reference to the state of Georgia in the inset. (Google n.d.)

In planning for field data collection, operational and geometric summaries of the two intersections were prepared. Crash data for a period of 3 years (2002, 2003 and 2004) were summarized by reviewing the incident reports. Collision diagrams for the two intersections were also prepared. These collision diagrams are given as Figure 3 and Figure 4 and were used to determine the critical conflict for which field data were to be collected, in this case the opposing left turn.

The data collection methodology and surrogate measures that need to be captured are determined by the critical conflict to be studied. For example, from Figure 3, it can be seen that there have been two fatal accidents between a left-turning vehicle and an opposing through vehicle at the intersection of US23/SR 365 and CR387 (Demorest Mt. Airy Highway) in Habersham County, Georgia. Although there are more rear end collisions, a crash between a left-turn vehicle and an opposing through vehicle is much more severe. So, the opposing left-turn conflict was determined to be the critical conflict for this study.

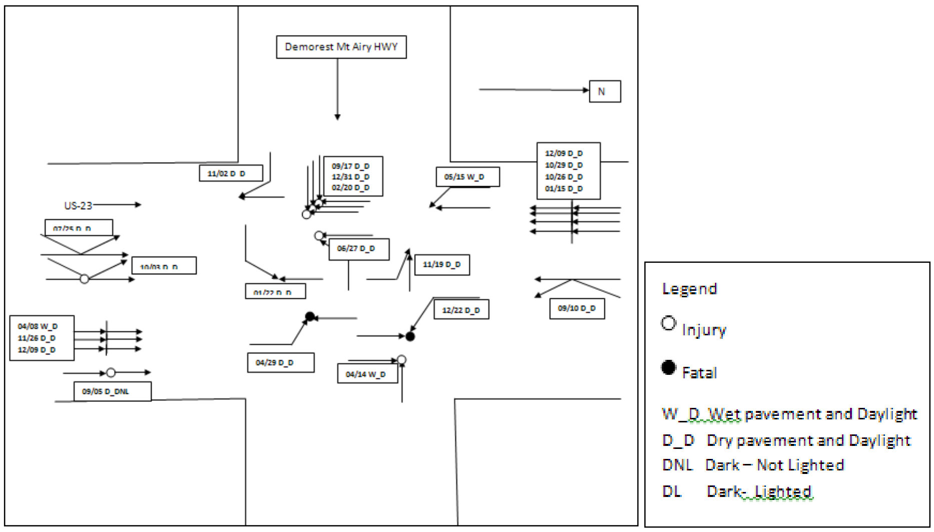


Figure 3 Collision diagram for the intersection of US23/SR 365 and CR387 (Demorest Mt. Airy Highway) in Habersham County, Georgia.

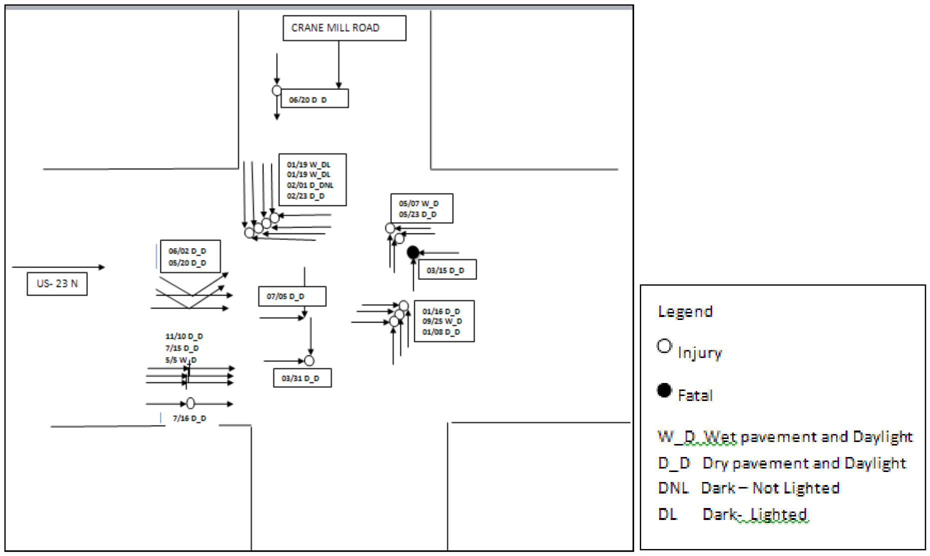
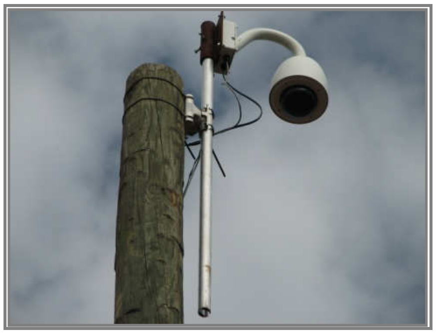


Figure 4 Collision diagram for the intersection of US23/SR 365 & CR395 (Crane Mill Rd) in Habersham County, Georgia.

Field Equipment

Video data used in this study were collected using a portable data collection station developed specifically for this study (Figure 5). Each portable station consists of a trailer equipped with solar panels that charge a set of six deep-cycle marine batteries which act to supply steady 12 Volt DC power. The data collection unit is equipped with a pan-tilt-zoom (PTZ) network camera that can either be mounted on the trailer mast or mounted on an adjacent pole. The use of a network camera, rather than an analog camera, allows for a direct connection of the camera to a low power notebook computer. The video stream is recorded on the notebook and periodically exported to an external hard drive. The setup also features a wireless cellular network connection that allows a user to remotely control the camera (change the view, turn off/on etc.) as well as control the recording process. The video data collection station is designed to provide high flexibility in the communication, recording, and camera control processes on a low power budget, allowing solar panels to act as the primary external charging source for an extended period.

(a) *(b)*



(d) *(c)*

Figure 5 Example Data Collection Unit (a) equipment trailer at base of pole, (b) Pole and the camera mounted on it, (c) trailer on-board equipment and (d) Closer view of the camera. (Photo credit: Guin, A. (2008))

Field Deployment

The study intersections are on a high-speed rural multilane highway with a speed limit of 65 mph (104.5 km/hr). The length of the intersection approach covered by the video is approximately 900 feet (274.32 m). This distance was selected to exceed the distance required for a vehicle to stop based on stopping sight distance criteria for the posted speed limit. A camera height test was conducted at the Georgia Tech Structures Laboratory to determine the optimal height of the camera. Video clips were obtained from the camera at heights ranging from 20 ft to 70 ft above ground level, in 10 ft increments. A 70 ft bucket truck was provided by GDOT to perform this study.

Analysis of the resulting video clips revealed that a minimum height of at least 40 ft to 50 ft was needed to ensure video clarity. However, even at this height a single camera was not sufficient to capture useable video over the 1000 ft zone (900 ft on approach plus intersection) established by the stopping sight distance criteria. The maximum useable range was about 600 ft and was further limited where the roadway sloped downward away from the camera location. Based on these results, it was concluded that a two camera solution would be required. One camera viewing across the intersection and a second camera located upstream to monitor approaching traffic. A feasibility study confirmed that it was possible to collect and analyze two synchronized camera video streams using the GT video analysis software.

A trailer configuration only allows for an approximately 18ft camera height that was insufficient for the purposes of the study. Given the time sensitive nature of the study and the possible delays that may be encountered in obtaining a mobile solution capable of a higher camera mounting height it was determined, in consultation with GDOT personnel, to use permanent pole placements at the Demorest-Mt. Airy Intersection to allow for more immediate progress in the study. As a result of a visit to the US23/SR 365 & CR387 (Demorest Mt. Airy Hwy) site by GDOT and Georgia Tech personnel, it was determined that four (4) 60 ft wooden poles would be used for camera mountings. The final installation included two poles located 300 ft downstream of the intersection on both sides of the intersection to capture a view of the left turn bay and the oncoming traffic and two poles located approximately 1100 ft from the intersection to capture the upstream traffic approaching the intersection. For this study, the cameras are mounted on wooden poles at a height of approximately 45’ above ground level. The camera views were overlapped to ensure accurate vehicle identification and video synchronization during the post-processing of the camera views. Figure 6 illustrates this configuration.

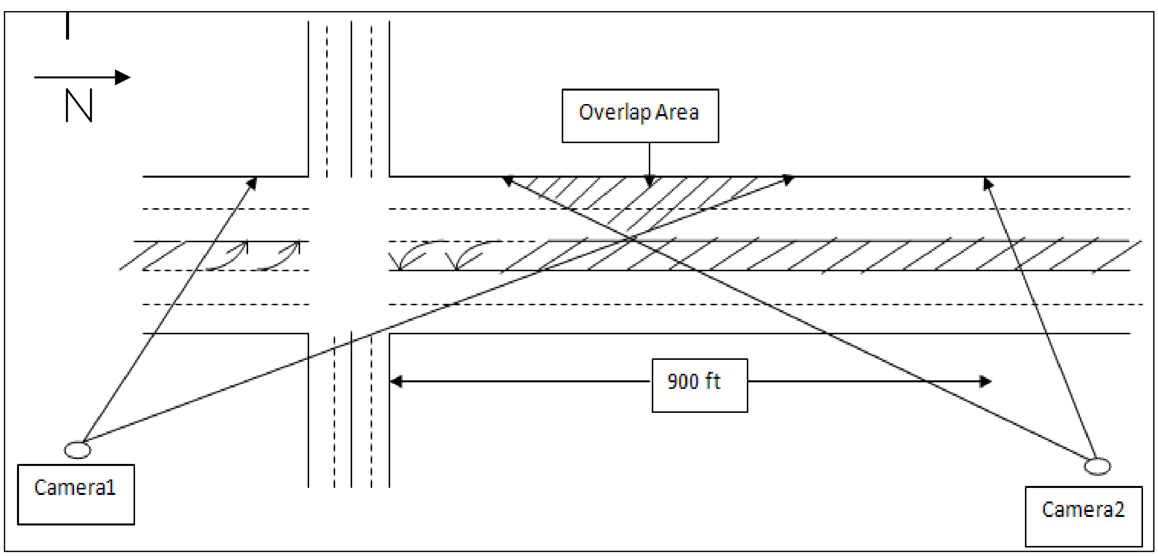


Figure 6 Field placement of the two cameras for the southbound approach

Data Reduction Software

Custom software was developed in Java™ and using the Java Media Framework™ (JMF) technology to allow for frame-by-frame review of the video. For any frame selected by the analyst, the software can extract both the frame number and a timestamp. This custom analysis software has two primary components – SaveGrid and ExtractData. SaveGrid allows the analyst to construct a video overlay containing detection lines separated by a set distance, 40ft in this case, based on known locations in the field of view. The known points were determined as part of the initial field survey used to establish the field equipment setup. The overlay is saved and is later re-loaded in the ExtractData module for extraction of data from the video. The red detection lines in Figure 7 illustrate a typical video overlay from the ExtractData module.

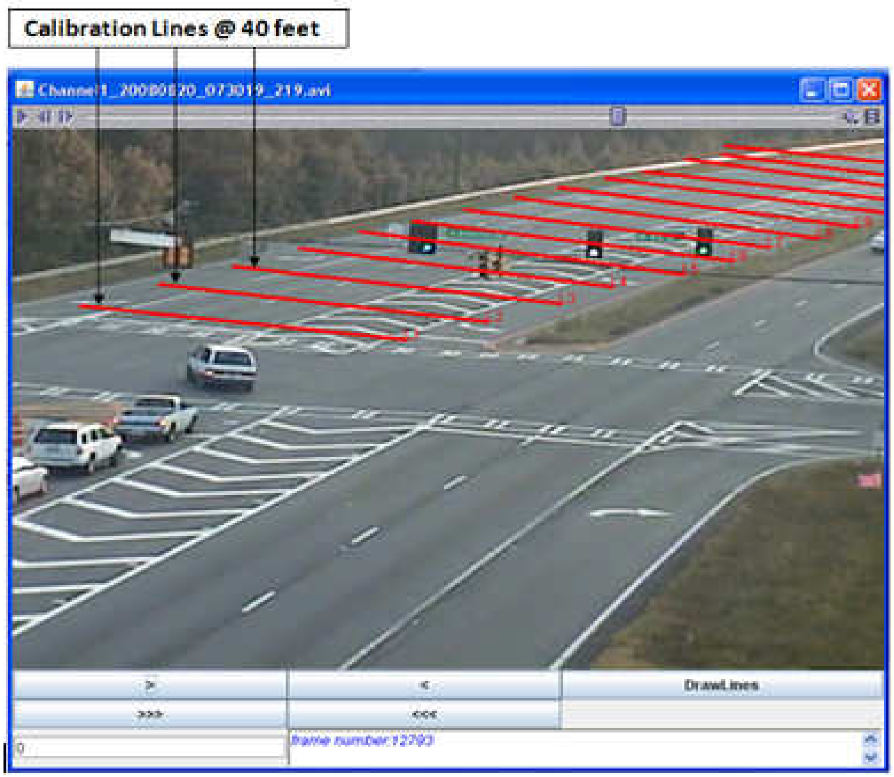
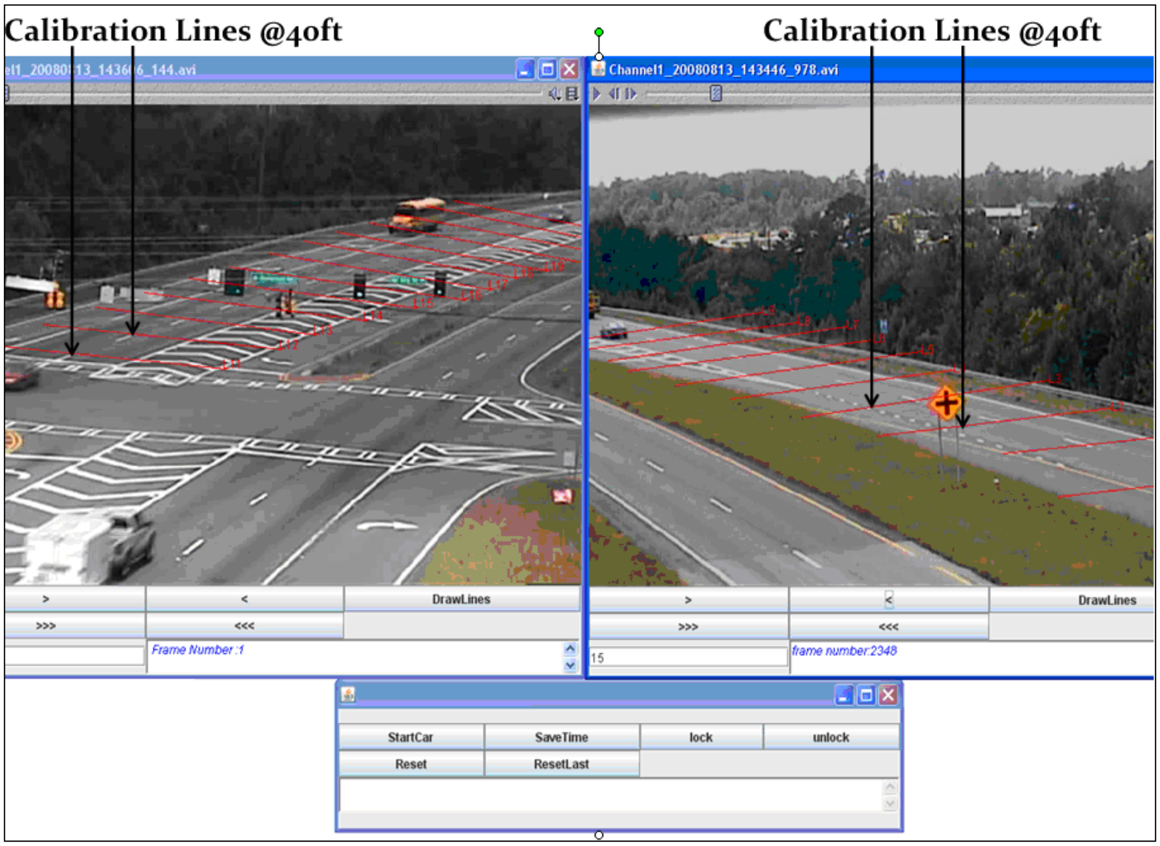


Figure 7 Example Screenshot of the Video Reduction Software

ExtractData is used to extract vehicle data from the video. The software allows the data analyst to step through the video frame-by-frame (both forward and reverse) as well as by a customizable multi-frame step for faster navigation. At the start of data reduction, the analyst imports the overlay detection lines created from the SaveGrid component. The analyst can then extract the time and position data of each vehicle as it crosses each detection line shown in the video overlay. Using frame-by-frame (or multi-frame) to step through the video, the analyst selects the frame in which the front tires of the monitored vehicle is positioned on the detection line of interest in the video. By using the "Savetime" button the analyst records the frame number, timestamp, and distance to the stop bar into the database.

The software has several reset options for handling analyst errors such as saving the incorrect frame or skipping a detection line. In addition, to minimize errors, the analyst tracks one vehicle through the entire intersection approach prior to processing data for the next vehicle. All data for a video is stored in a comma-separated-value ASCII file for subsequent analysis.

As stated previously, two cameras are used to capture each intersection approach. To process the vehicle data, the video from the two cameras must be synchronized. Figure 8 provides an example of the video from the two cameras monitoring the southbound approach. Figure 8 (a) shows the downstream portion of the approach (i.e. the portion closest to the intersection) and Figure 8 (a) shows the upstream portion of the same approach. Note that in this example the viewing angles are not from the same direction, that is, the upstream is viewed from the South end while the downstream is viewed from the North end. The top right corner in Figure 8 (a) and the top left corner in Figure 8 (b) constitute the region of overlap.



(a) *(b)*

Figure 8 Example Approach Camera Views using Two Cameras: (a) View of Upstream Portion of Appraoch, and (b) Example of Downstream Portion of Approach.

The videos are initially synchronized by manually matching the position of a test vehicle in the two videos at an overlapping detection line, i.e., a set distance from the intersection captured in both videos. Once the videos have been synchronized, the ExtractData module maintains synchronization of the two videos both forward and backward for review by the analyst. Provision is also made to maintain synchronization through the transition from one video clip to the next since the beginning timestamps of the clips from the two sources are not expected to match exactly.

Data Sampling

For each mainline approach to the intersection, a minimum of one week of video was recorded for each analysis time period (i.e., before and after treatment installation). This creates a data set representing each day of the week. To minimize chances of data corruption and data loss, video is stored as a series of 10 minute clips. For each measurement day, approximately 16 hours of video was collected during the daylight (and twilight) hours, resulting in ninety-six (96) 10-minute video clips. Each 10-minute video clip required approximately 4 hours of analyst time for data reduction (depending on traffic flows additional time could be required) using the data reduction software.

As this reduction process is highly resource intensive, it is not possible to extract data from all video clips within a reasonable time period. Thus, a video sampling plan was adopted to capture a cross section of the recorded video. A single 10 minute video clip was selected from each hour as representative of data for that hour. The ten minute period selected for each consecutive hour is shifted by ten minutes in an attempt to avoid a bias over the day. For example, if the first 10 minute video selected for a given day has a start time of 6:50 AM, the next video selected for the same day would be 7:40 AM, then 8:30 AM and so on. Similarly for the next day, the first video selected has a timestamp of 6:40 AM, then 7:30AM and so on.

To obtain a baseline dataset of the behavior of vehicles approaching an intersection that was not influenced by potential opposing left turns, the time position data was extracted for all the through vehicles approaching the intersection according to the sampling plan in the previous paragraph, for a representative day. Then, the dataset is screened and only those vehicles that met the following conditions are retained for analysis:

- Subject vehicle did not have any opposing left-turning vehicles at the intersection during the entire period of traversal of the vehicle through the observed section.
- Subject vehicle's passage through the intersection was uninterrupted, i.e., did not need to stop for the signal or a queue.

Analysis of these vehicles allows for a determination of driver behavior in the absence of left turning vehicles. For the remaining days of the analysis period, data was extracted (according to the above sampling plan) for only those through vehicles satisfying the following conditions:

- There was an opposing left-turning vehicle that crossed the intersection while the through vehicle is within the approach area under study.
- The opposing left and through vehicle are both facing a green signal indication, thus the opposing left should only proceed if it has a sufficient gap.
- There is no standing queue of through vehicles at the intersection (such as the tail of a queue formed during the red phase) which would affect the behavior of the approaching through vehicle.

These conditions were set to capture the behavior of vehicles directly related to the objective of this effort, i.e. measuring the effect of the installed treatments on the vehicle behavior during potential conflicting intersection movements. By extracting data exclusively for these vehicles during the remaining 10 minute clips, the data extraction time per 10 minute clip is reduced, allowing for more vehicles of interest to be sampled.

Additional Data Processing

The video analysis software was also used to evaluate the Post Encroachment Time (PET) distribution. PET refers to the time lapse between the end of encroachment of a turning vehicle and the time when the through vehicle enters the potential area of collision. PET is a potential surrogate measure of safety. Any increase in the level of alertness in the drivers resulting from the treatments can be expected to be reflected in an increase in the PET.

Since there are two through lanes at the intersection of interest, there are two areas of conflict. These two areas are marked on the videos using the SaveGrid software component prior to starting the analysis. Next, using the ExtractData software component the analyst extracts the time stamps of the end of encroachment of the left turning vehicle and the time of arrival of the through vehicle at the area of conflict. The difference between these timestamps is the PET. These zones are illustrated in Figure 9.

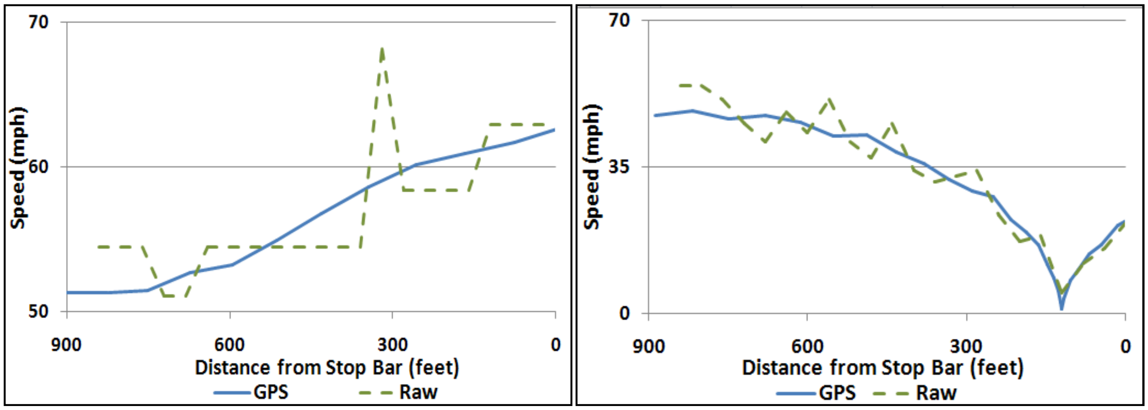
Figure 9 Screenshot of Software Setup for Post Encroachment Time Data Extraction

Smoothing Algorithm

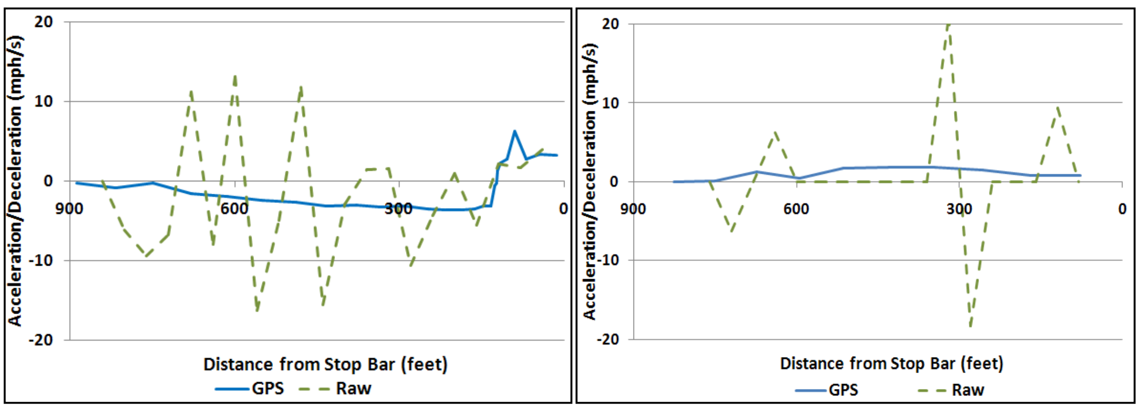
Geographic positioning system (GPS) equipped probe vehicles are commonly used to collect ground truth data for validation of speeds determined by other methods. The GPS equipment provides second-by-second location (latitude and longitude) data of the probe vehicle. These positions allow for the creation of a time-space diagram from which a velocity profile of the vehicle can be derived. In turn, this velocity profile can be compared to results obtained from other methods (video extraction in this case) to validate the accuracy of the second data collection method.

To verify the accuracy of the video data collection methodology and to obtain information necessary to define the optimal smoothing algorithm, (GPS) probe vehicle data were collected during the sampling period. Typical comparisons between these GPS probe vehicle runs on the study site and the speeds generated using the software are shown in Figure 10.

These results show generally good agreement between the two approaches with very high scatter in the video based approach. This high scatter is not unexpected. The process of generating speed from video at a frame resolution of 30 frames per second gives discrete speed readings that result in noise in the data. These irregularities are a result of the requirement in the video collection methodology that there be an integer number of frames between subsequent measurements. This requirement results in discrete values of the speeds that can be reported based on the frame rate and the distance between the video reference lines (40 feet in this study). Some additional irregularities are the result of inherent error in identifying the 1/30 of a second frame in which a vehicle crosses a detector line. As the distance from the camera increases, the potential for this type of error increases due to the perspective view. These errors may be largely eliminated by proper data filtering and smoothing algorithms.



(a)



(b)

Figure 10 Example graphs showing (a) vehicle speed and (b) acceleration/deceleration profiles obtained by reducing the video data using custom software and comparing them with those obtained from GPS data.

The smoothing algorithm is chosen such that it removes the nominal irregularities in the raw data due to discretization of the speed values, but does not smooth out the higher values of accelerations or decelerations of the vehicles. To obtain the algorithm that satisfies this requirement, a heuristic approach has been adopted. Various smoothing algorithms have been applied on the speed and acceleration data obtained. The simplest algorithm consists of an un-weighted moving average, replacing each point in the data with the average of ‘m’ adjacent points where m is a positive integer called the smoothing width. For example, for a 3-point smooth,

$$S_j = (Y_{j-1} + Y_j + Y_{j+1})/3$$

where S_j is the j^{th} point of the smoothed data, Y_{j-1}, Y_j and Y_{j+1} are the $j\text{-}1^{th}$, j^{th} and $j+1^{th}$ data points before smoothing. Three-point, five-point, and seven-point moving average algorithms have been tested. In addition, weighted average smoothing functions are also tested. A weighted average is any average that has multiplying factors to give different weights to different data points. For example, the “1+3+5” weighted average for smoothing the value of Y_4 (i.e. S_4 (1+3+5)) is the average of the value of Y_4, the 3-point moving average, and 5-point moving average. The expression for S_4 is obtained as:

$$S_4\ (1+3+5) = (Y_4 + S_4(\text{3-point moving average}) + S_4(\text{5-point moving average}))/3$$
$$= (3Y_2+8Y_3+23Y_4+8Y_5+3Y_6)/45$$

where S_j is the smoothed j^{th} point, Yj-2, Y_{j-1}, Y_j, Y_{j+1} and Y_{j+2} are the $j\text{-}2^{th}$, $j\text{-}1^{th}$, j^{th} $j+1^{th}$ and $j+2^{th}$ data points before smoothing. So, it is clearly seen that different weights are assigned to different raw data points for finding the weighted average. This approach gives the highest weight to the central value and the weight decreases farther from the central value. The following smoothing algorithms were tested on the data.

- Three-point moving average
- Five-point moving average
- Seven-point moving average
- 3+5 weighted average
- 3+5+7 weighted average
- 1+3+5+7 weighted average

Figure 11 shows the results of applying the various smoothing algorithms described above to the raw speed data and comparing them with the speed profile obtained from GPS data for a sample vehicle run. Similarly, Figure 12 shows the results of applying various smoothing algorithms to the raw acceleration/deceleration profile and comparing them with the profile obtained from GPS data. Visual inspection of these figures indicated that the "3+5+7" smoothing algorithm produces speed and acceleration-deceleration profiles closest to the ground truth data (GPS data). These results are marked by the red outline in both Figure 11 and Figure 12.

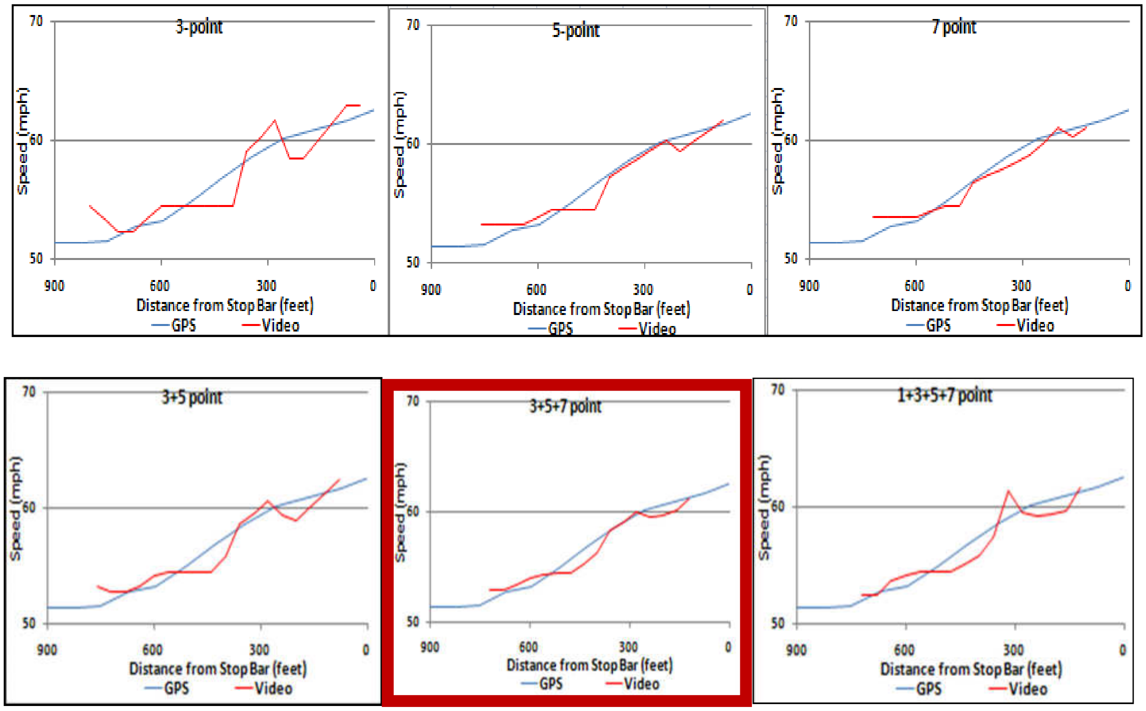


Figure 11 Plots showing the vehicle speed profiles after applying various smoothing algorithms on the raw data

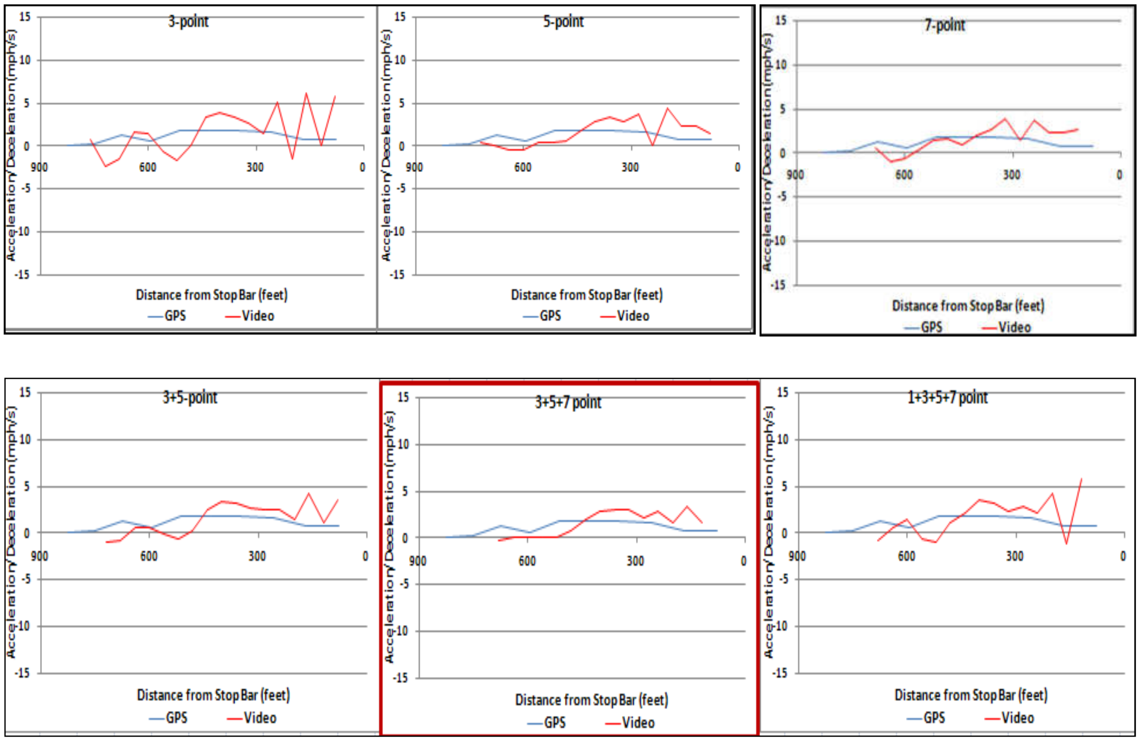


Figure 12 Plots showing the vehicle acceleration/deceleration profiles after applying various smoothing algorithms on the raw data

In addition to visual inspection, mean-squared errors (MSE) were calculated for the speed and acceleration-deceleration data obtained from video assuming that the GPS data is accurate. Figure 13 shows the comparison of four independent runs of the GPS probe vehicle through the 900 feet approach to the intersection in tabular form. It can be seen from the table that for the acceleration-deceleration data, "3+5+7" smoothing gives the least MSE for all four runs while for speed, "3+5+7" gives the least MSE for two runs while it gives the second least MSE for the other two runs. Based on these data, the "3+5+7" smoothing algorithm was selected as the optimal smoothing algorithm for the speed and acceleration-deceleration data of the sampled vehicles obtained from the video reduction. The results of these analyses are discussed in the next section.

Source	Speed MSE				Acceleration/Deceleration MSE			
	Run1	Run2	Run3	Run4	Run1	Run2	Run3	Run4
Raw Data	4.2064	223.70	6.1851	7.7086	34.628	221.15	54.943	59.573
3-point	2.3092	2.7471	2.0545	2.3736	3.2787	14.240	4.3531	6.8987
5-point	2.1231	1.2894	1.4883	0.7152	1.1828	4.1645	2.1921	2.3559
3+5 point	2.1249	1.4812	1.496	1.0661	0.9090	4.0613	1.0823	2.8395
7-point	2.0728	1.5019	1.3690	0.4884	1.1237	3.5335	1.2424	2.1304
3+5+7 point	2.0293	1.3009	1.115	0.5345	0.8272	1.6524	0.5876	1.8850
1+3+5+7 point	2.1102	1.7117	1.3819	1.1662	1.9950	3.4722	3.5620	5.7996

Figure 13 Table showing the Mean Squared Error values for various smoothing algorithms assuming GPS data as the ground truth

Results

Analytical Measures

This section describes the results of the analysis of the before and after treatment data for the intersection of US23/SR 365 & CR385 (Demorest Mt. Airy Hwy) for both the northbound and southbound approaches. Initial analysis demonstrated that the vehicles undergo minimal acceleration or deceleration activity when approaching a green signal where no opposing left-turn vehicles are present and no standing queue exists. Thus, unless otherwise noted, the analysis included here includes only data from through vehicles when a conflicting left turn is present and there is no queue or signal change to interfere with the movement of the through vehicle.

The behavior of these through vehicles facing opposing left-turning vehicles is captured in three quantitative measures:

- acceleration/deceleration values of the through vehicles,
- Post Encroachment Time (PET), and
- speed at which the through vehicles enter the intersection.

Each of these measures is a potential indicator of conflicts and surrogate for the intersection safety. Changes between the before and after treatment observations in any or all of these measures are likely to be indicative of potential treatment impacts.

For this analysis, speed and acceleration/deceleration profiles for through vehicles are measured from the boundary of the intersection proper (defined as the stop bar) to a position approximately 900 ft upstream. Raw data collection consisted of time versus position data collected over this data collection zone. The data collection zone was divided into 40 ft intervals with the time a vehicle crosses each 40 ft marker determined through the use of video recordings. Thus, over the 900 ft data collection area, speed and acceleration/deceleration trajectory data are collected at approximately 25 discrete data points.

It is noted that for the given intersection, traffic demands, and data collection periods, conflict opportunities (i.e. the arrival of a through vehicle with no standing queue on the through approach and an opposing left turn vehicle present) were greater on the southbound approach. In the following analysis, before and after southbound results are based on 300 and 297 through vehicles, respectively, while the northbound before and after results are based 42 and 44 through vehicles, respectively.

Through Vehicle Acceleration and Deceleration

Two complementary analyzes of the through vehicle acceleration/deceleration data were conducted. In the first, the before and after distribution of the acceleration/deceleration profile data points are compared. In the second, only the maximum acceleration/ deceleration value in each through vehicle profile, as opposed to all the data points in the profile, were considered.

The before and after frequency distribution of the through vehicle acceleration/deceleration data for the southbound and northbound approaches are shown in Figure 14 and Figure 15, respectively. It is noted that frequencies in these plots are normalized.

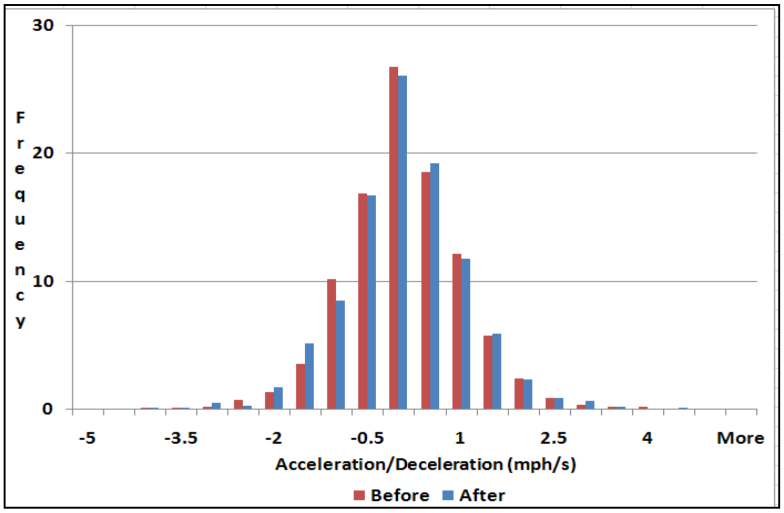


Figure 14 Normalized histogram of the acceleration/deceleration profiles, southbound approach

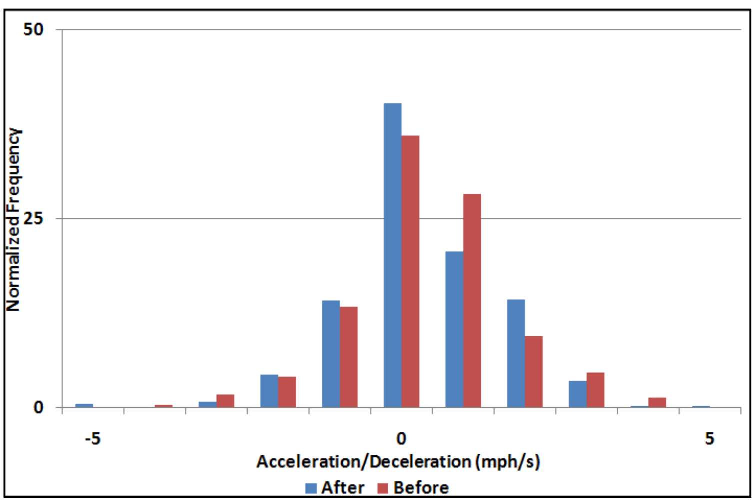


Figure 15 Normalized histogram of the acceleration/deceleration profiles, northbound approach

It is seen in both Figure 14 and Figure 15 that the through vehicle acceleration/deceleration distributions before and after applying the treatment are very similar. The southbound data plot (Figure 14) potentially demonstrates a slight shift to higher decelerations in the after data. Northbound data (Figure 15) contains almost no notable differences in the deceleration data, with some slight increase in acceleration in the after data. It is noted that all before and after deceleration data falls within the comfortable deceleration value of -6.81 mph/s (-10 ft/s/s) typically utilized in intersection signal design. Only approximately 2% of the measured decelerations exceed -4 mph/s.

Cumulative distribution functions (CDF) of the before and after acceleration/deceleration data are plotted in Figure 16 (southbound) and Figure 17 (northbound).

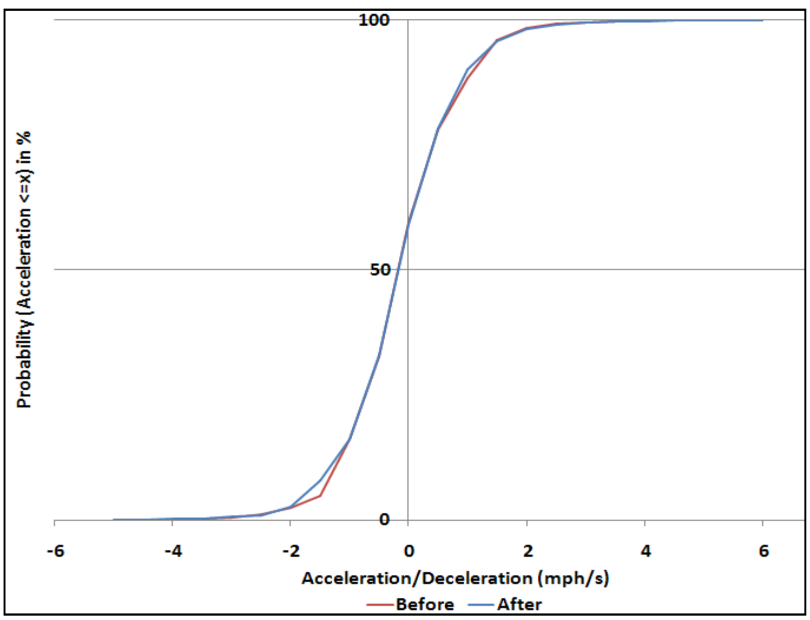


Figure 16 CDF of the acceleration/deceleration profiles, southbound approach

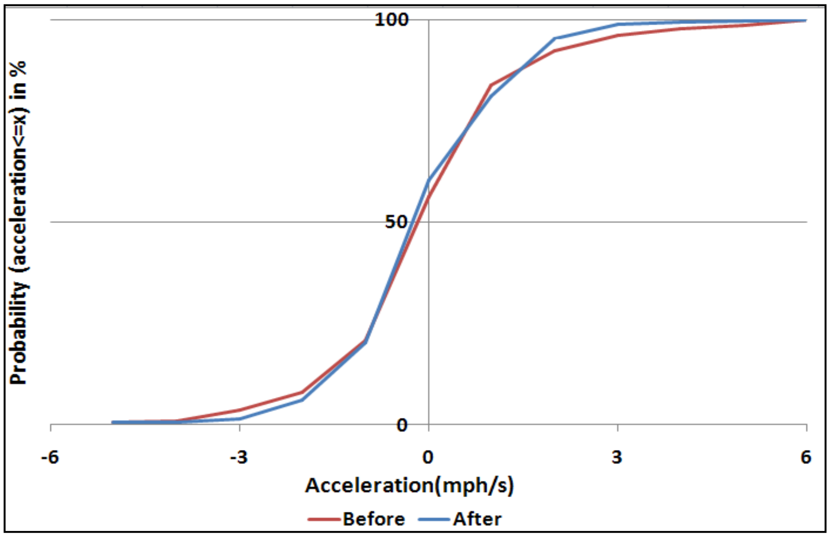


Figure 17 CDF of the acceleration/deceleration profiles, northbound approach

The southbound CDF plot (Figure 16) shows that the probability of having decelerations in the range of -1 to -2 mph/s is marginally higher in the after treatment data than in the before data. Other than this difference, the two curves consistently overlap, implying that any difference in the distributions of accelerations and decelerations in the before and after southbound data is either very minor or non-existent. The CDF plot of the northbound before and after data (Figure 17) indicates a slight decrease in the likelihood of decelerations rates in the -1 to -4 mph/s range in the after data. However, the likelihood of decelerations greater than -4 mph/s is same in both the before and after data.

As stated, the first acceleration/deceleration analysis utilized the data points over the entire vehicle trajectory as the vehicles approach the intersection. However, a conflict may be characterized by large decelerations due to the application of brakes to avoid a collision. Therefore, we also consider only the maximum deceleration rate of the through vehicles. A significant difference in the before and after treatment distribution of maximum decelerations may indicate a change in the number or severity of conflicts.

The normalized maximum decelerations frequency distribution plot for the southbound approach (Figure 18) shows a potentially slight increase in the recorded maximum deceleration in the after treatment data collection, however, the magnitude is likely insignificant. The northbound maximum deceleration data (Figure 19) shows higher frequency for the before treatment data in the range of -3 mph/s to -5 mph/s but the after data has higher frequency for maximum decelerations greater than -5 mph/s.

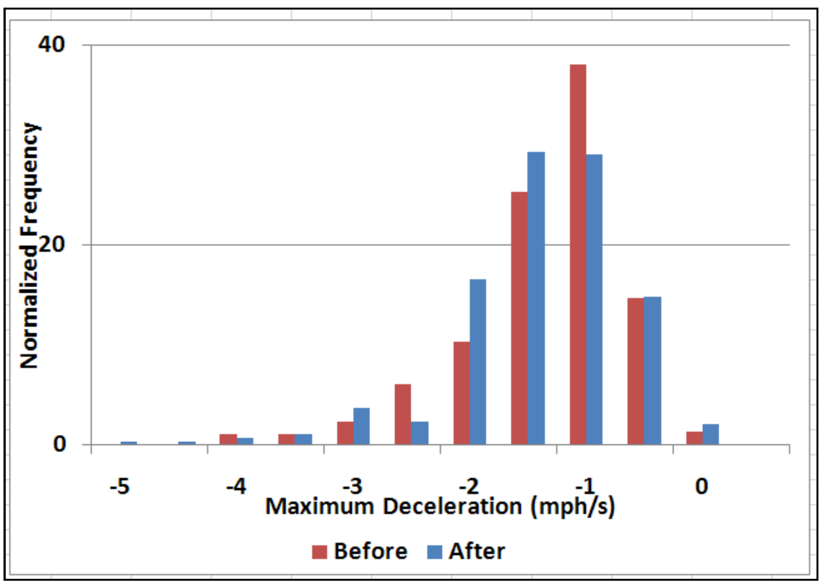


Figure 18 Normalized histogram of the maximum decelerations, southbound approach

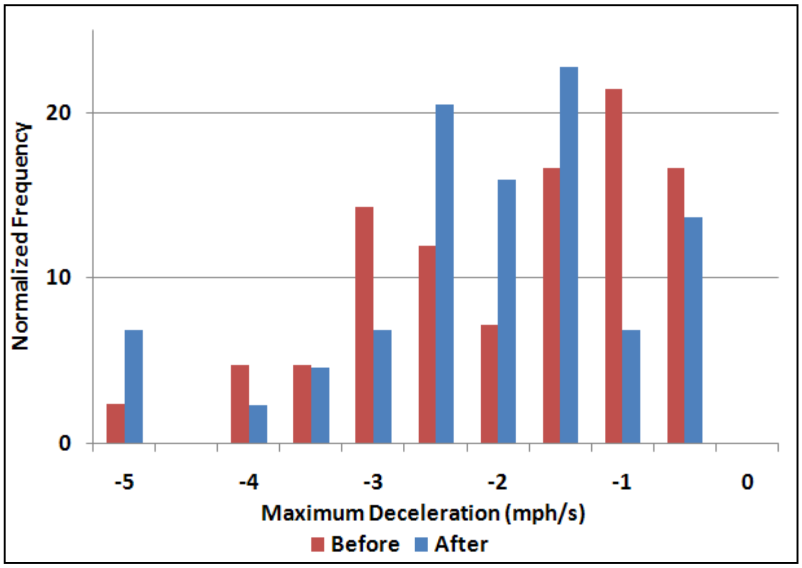


Figure 19 Normalized histogram of the maximum decelerations, northbound approach

Similar interpretations can be derived from the graphs of the CDF of the through vehicles' before and after treatment maximum decelerations on the southbound (Figure 20) and northbound (Figure 21) approaches.

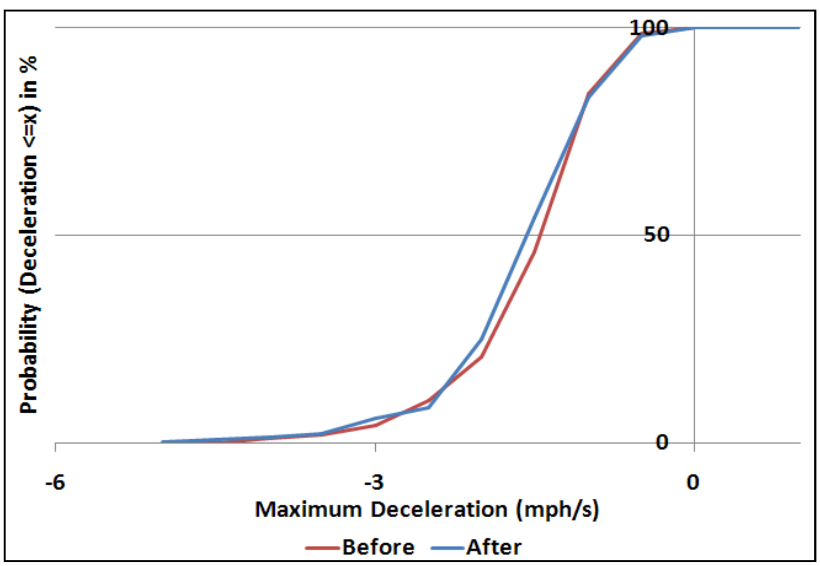


Figure 20 CDF of the maximum decelerations, southbound approach

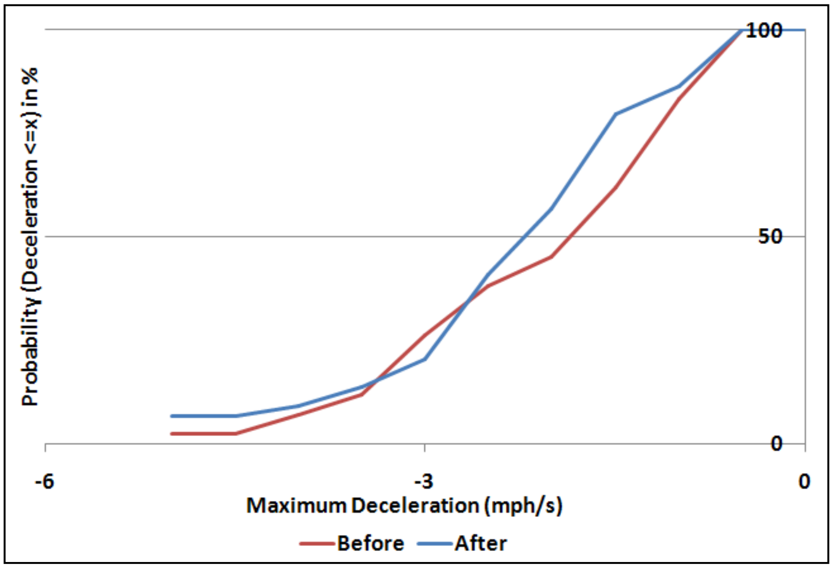


Figure 21 CDF of the maximum decelerations, northbound approach

Figure 20 (southbound approach) shows that there is a minimal difference in the range of -1 mph/s to -2 mph/s. However, there is no perceivable difference in the CDF of the deceleration values greater than -3mph/s. Figure 21 (northbound approach) shows only a small difference in the CDF values when decelerations are more than -3 mph/s. There are again differences in the lower range deceleration rates; however, the trend is opposite of that seen on the southbound approach. Thus, similar to the aggregate acceleration/deceleration data, the maximum deceleration data contains no significant changes that would indicate a difference in either before and after treatment conflicts or safety performance.

Post Encroachment Time

Post Encroachment Time (PET) was the next surrogate measure considered in the analysis. PET is the time lapse between the end of encroachment of the turning vehicle and the time that the through vehicle arrives at the potential point of collision. Any increase in the level of alertness in the drivers resulting from the treatments can be expected to be reflected in an increase in the PET. Figure 22 shows the normalized frequency of the PET values between the left turning vehicles and the through vehicles for the southbound approach. Figure 23 shows the PET distribution for the northbound approach.

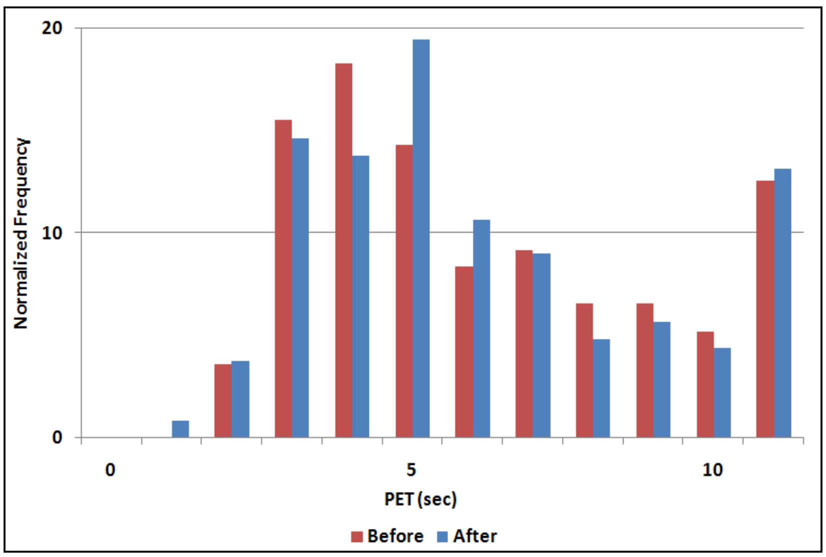


Figure 22 Normalized histogram of the PET values, southbound approach

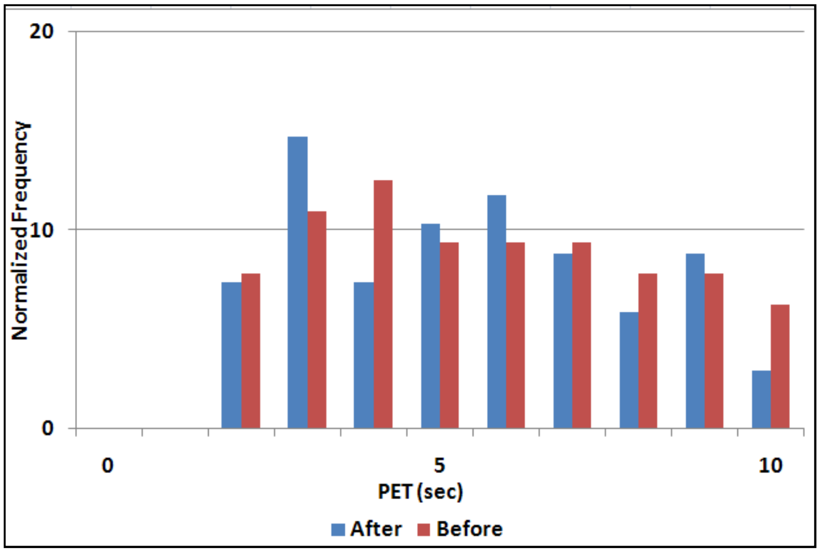


Figure 23 Normalized histogram of the PET values, southbound approach

Figure 22 shows a small shift in the PET values from the range 4-5 sec to the range 5-6 seconds in the southbound direction. There is no appreciable change from the before to after treatment periods in the distribution of PET values greater than 6 seconds. The northbound data (Figure 23) shows the reverse trend, with an increase in the number of PET values in the lower range (3-4 seconds) in the after data. Again, there is no notable trend in the higher PET values. Literature suggests that critical PET values fall within the range of 3 to 5 seconds. While some differences between the before and after treatment data are witnessed in this range there is no consistent pattern between the northbound and southbound approaches.

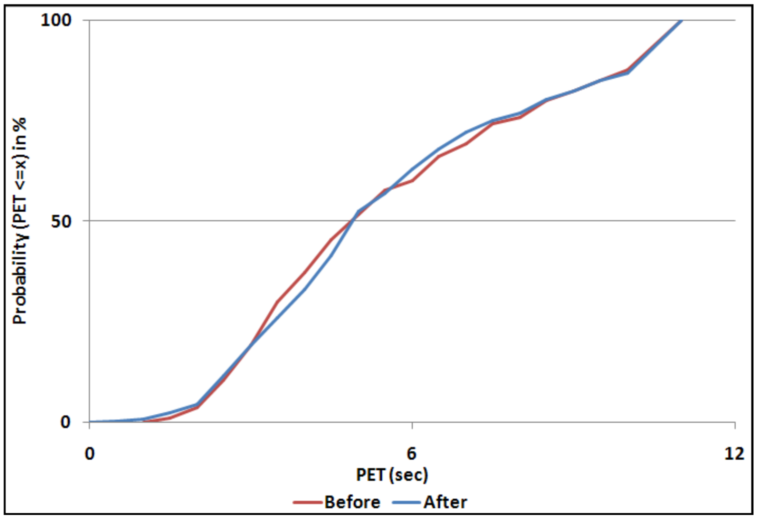


Figure 24 CDF of the PET values for the before and after data, southbound approach

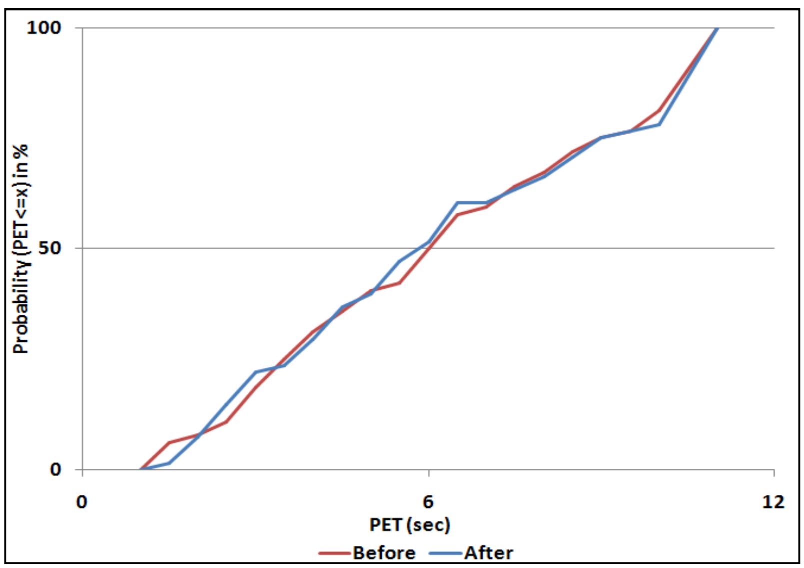


Figure 25 CDF of the PET values for the before and after data, northbound approach

The southbound PET CDF (Figure 24) shows a similar picture, again with a slight shift to higher after treatment PET values in the 3.5 to 7.5 second range. The northbound PET CDF (Figure 25) demonstrates no consistent shifting between the before and after PET behavior. As with the acceleration/deceleration observations, the observed PET differences before and after treatment are all minor (within a few percent), likely indicative of expected minor variability resulting from the data collection procedure and underlying randomness in the driver's behavior rather than a systemic treatment effect.

Through Vehicle Speeds

Figure 26 shows the southbound approach before and after treatment speed distributions for through vehicles as they enter the intersection proper. Some shifting of the speed distribution to lower values, on the order of 3 mph, is seen in the after treatment. The northbound data (Figure 27) shows generally the opposite trend with a decreased likelihood of lower speeds after the treatment installation. However, it is noted that the northbound approach range of variation of the speeds is reduced in the after data.

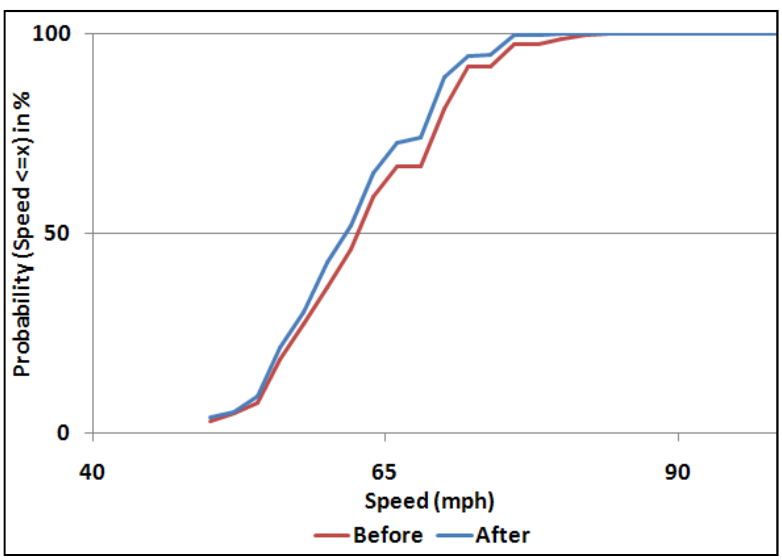


Figure 26 Speed of through vehicles entering intersection proper, southbound approach

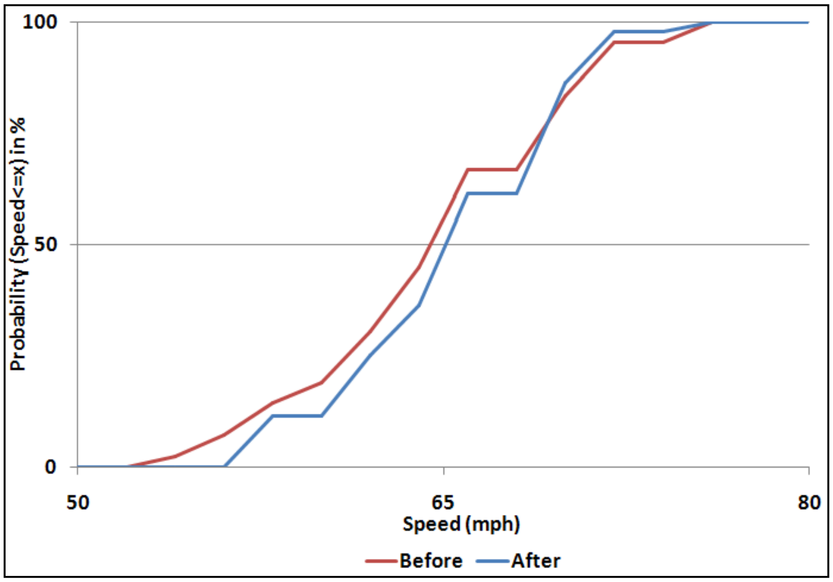


Figure 27 Speed of through vehicles entering intersection proper, northbound approach

Findings of the Habersham Study

For neither the northbound nor southbound approach data do the surrogate measures considered show that the treatment has any significant effect on the behavior of the through vehicles (in the presence of a left turn vehicle and no approach queue) or indicate a likely change in the intersection safety for the data collected at US23/SR 365 & CR387 (Demorest Mt. Airy Hwy). All three surrogates considered (acceleration/deceleration values, PET values, and through vehicle intersection speeds) show only minor differences in the distributions of the before and after data. The differences, if any, are small and often statistically insignificant (oscillating around zero), likely indicative of expected minor variability resulting from the data collection procedure and underlying randomness in the driver’s behavior rather than a systemic treatment effect.

After completion of the analysis of these data, it appeared highly likely that extensive analysis of the US23/SR 365 & CR395 (Crane Mill Rd) intersection would yield the same conclusion. That is, there were no statistically significant differences in before and after treatment results and that the currently implemented treatment would be unlikely to meaningfully impact intersection safety. Upon recommendation of the research team and GDOT approval, analysis of the US 23/ SR 365 & CR 395 (Crane Mill Rd) site was terminated and second phase project resources were redirected to seek different potential treatments that could be utilized in Georgia on high speed signalized and unsignalized intersections and to further develop the analytical methods to evaluate these treatments. The results of these efforts are discussed in the next section.

THE PET STUDY

Summary of Results

As a follow up to the Habersham Study, the use of Post Encroachment Time (PET) data as a surrogate measure was further explored. The objective of this investigation was to determine the utility of using PET to rapidly determine the potential safety impact of a treatment in a before/after analysis or as a ranking tool of safety differences between intersections. For this investigation, data were collected at two pairs of intersections. Each of the pairs was selected to be of similar geometry and volumes but of very different crash rates.

The first pair of intersections was both located along SR10 at Grayson Parkway and at Henry Clower Blvd/Oak Road. As in the Habersham study, data collection focused on the conflict of through vehicles versus the opposing left turn. For these intersections there was not a significant difference in the PET distributions in the critical range (sub three second) even though the ten year crash frequencies differed by a factor of approximately six (11:63).

For the second pair of intersections, the criteria that the intersections be along the same corridor was relaxed and intersections with higher differences in crash frequencies were selected. The high accident intersection selected was Wieuca Road and Roswell Road in the City of Atlanta (123 crashes between through and opposing left turn vehicles between 2000 and 2009) while the low accident intersection was at Buford Highway and Sugarloaf Parkway in Gwinnett County (7 crashes over the same period). In this case, the higher accident intersection showed significantly more critical (sub three second)

PET values than did the safer intersection. This ratio (about 3.3 times), while substantial, was significantly less than the nearly twenty fold difference in crash frequencies. Thus, while for the given intersections, PET has demonstrated the potential to distinguish between highly significant safety differences. It remains uncertain what level of safety difference may be identified. Additional research will be needed before PET can be viewed as a robust quantitative surrogate measure for estimating intersection safety.

Introduction

From the Habersham study, it was not clear why the surrogates considered did not show any significant difference before and after the application of the treatment. It is speculated that this could be because:

(i) the treatment is so subtle that it did not have any discernible effect on the interactions between left-turn and opposing through vehicles, or

(ii) the considered surrogates are not effective in capturing these interactions, or

(iii) a combination of both (i) and (ii).

Hence, for the next phase of the research, it was decided to evaluate the effectiveness of these surrogates by collecting surrogate data at additional intersections having high, medium, and low crash frequencies. However, the Habersham study demonstrated that collecting acceleration-deceleration profiles was both an equipment and labor intensive task. As such, a replication of this study to capture the same surrogate measures for multiple locations is likely cost prohibitive for most routine circumstances. Collection of speed profile data also suffers from these limitations. Spot speed could be a better surrogate in terms of labor and equipment requirements but a definite boundary value that differentiates a crash or non-crash event cannot be readily defined for this measure.

Given these observations, the experience from the Habersham Study, and previous research works, it was hypothesized that PET had the highest likelihood of proving to be a usable and cost-effective surrogate measure. Firstly, PET is relatively easy to measure as it requires collecting only two timestamps for each PET data point. Secondly, PET has a direct association with incidents as a PET value of zero differentiates crash and non-crash events. Therefore, it was decided that the next phase of this research would focus on evaluating the effectiveness of PET as a surrogate measure for safety.

Thus, this portion of the research project delves deeper into the effectiveness of PET as a surrogate measure of safety. As in the Habersham study, the conflict being studied is between a left-turn vehicle and an opposing through vehicle at a signalized intersection. This task involved data collection at additional intersections, evaluating the properties and distribution of PET, and finally evaluating its effectiveness as a surrogate measure. This study, in addition to developing a cost-effective data collection procedure for obtaining a statistically sufficient PET data sample, was designed to evaluate the potential use of PET as an effective surrogate measure of safety.

Research Approach

The primary data collection methodology for the PET Study was video recording of the traffic streams from an elevated viewpoint. The custom frame-by-frame video reduction software program developed for the Habersham Study was further adapted to increase the efficiency in extracting PET data. Significant effort was devoted to developing a data collection scheme with a minimum level of equipment deployment, eliminating the need for permanent or high mounted equipment installations. For instance, in this effort all video data collection was accomplished through the use of standard tripods, with no additional height required.

It was expected that one of the major applications of PET will be to determine the potential effectiveness of any safety treatment or countermeasures applied at an intersection without having to wait the typical three year period for collecting the incident data. In such an application, the intersection conditions before and after the treatment would be the same, except for the treatment and any minor volume fluctuations. Thus, the difference in the before and after PET data should be attributable primarily to the effect of the treatment, potentially allowing PET data to be an accurate indicator of safety differences. However, in this effort it was not possible to collect before and after treatment data at sites where treatments were applied. Thus, to evaluate the effectiveness of PET as a safety indicator intersection pairs that had similar operating conditions but different crash frequencies were selected.

In addition, the conflict between left-turning and opposing through vehicles is a primary conflict in which safety may potentially be reflected by the PET data. Therefore, the frequency of crashes which occurred due to this conflict was directly considered. To reduce potential confounding variables in the paired intersection PET analysis (such as different driver populations, AADTs, intersection geometries, etc.) a corridor level analysis of crash frequencies was used to select the first candidate intersection pair. The first pair was selected to maximize the similarity in characteristics while having substantially different crash frequencies allowing for a pair-wise comparison to evaluate the effectiveness of PET. As will be discussed in the following sections for the second intersection pair the requirement for the paired intersections to be on the same corridor is relaxed, while maintaining similar geometries, ADTs, etc.

Accident records for the years 2000 through 2009 were processed to generate candidate intersections for the PET study. Data were analyzed from crash records from the sanitized crash database provided by GDOT and also using the CARE software (CARE CRASH ON-LINE ANALYSIS n.d.). Data were collected primarily during peak and off-peak periods, under day-light, non-inclement weather conditions.

The first selected intersection pair was GA 10 (Main St) at Henry Clower Blvd/Oak Rd and GA 10 (Main St) at Grayson Pkwy in Gwinnett county, Georgia. The distance between the intersections is 1.2 miles. The intersections have similar AADT counts, signal control, and geometries but have different crash frequencies between left-turn and opposing through vehicles. Initial video data were collected during off-peak hours (data collection dates/times listed in Data Collection and Results). It was decided to collect data during off-peak hours as few sufficient gaps are available for the left-turn vehicles to turn during the peak hours. Data collection at both intersections was carried out simultaneously to ensure consistency in the driver population.

Video data collected at the two intersections were reduced in a laboratory environment using a modified version of the custom video reduction software developed earlier. The images below (Figure 28 and Figure 29) show the views of the intersections as seen with the custom software interface. A screenshot of the intersection of GA 10 at Grayson Pkwy is shown in the Figure 28. The red lines on the picture represent the paths of the through vehicles and the blue numbers on the screen represent direction identifiers for user input. For example, Eastbound-Left is entered into the software as 62 (from: 6, to: 2), Eastbound-Through as 64 etc. Figure 29 shows a similar image of the Henry Clower Blvd. intersection.

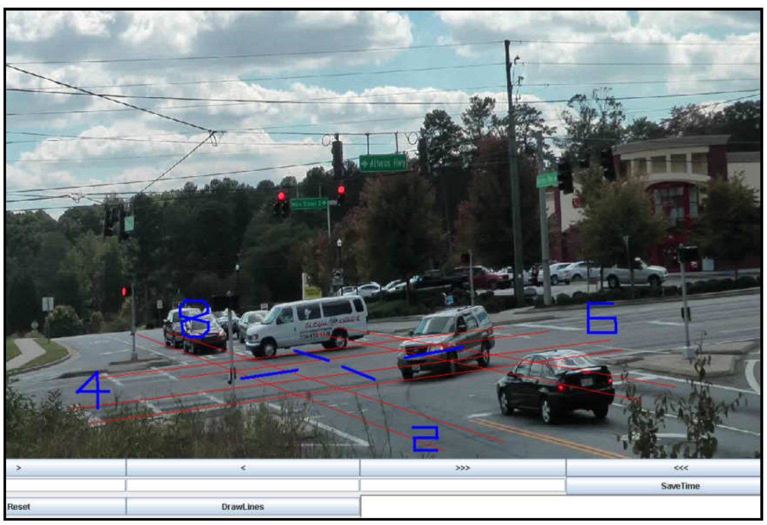


Figure 28 Intersection of GA 10 with Grayson Pkwy

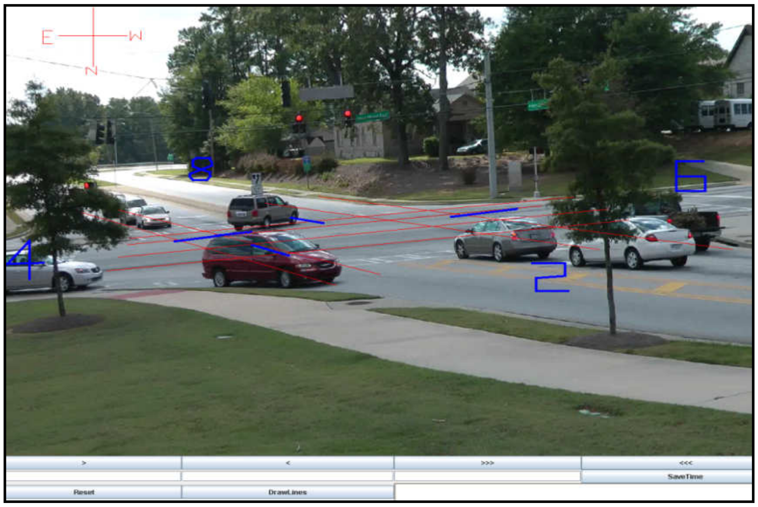


Figure 29 Intersection of GA 10 with Henry Clower Blvd/Oak Rd

Data Collection and Results

The crash data shows that the ratio of the number of crashes which occurred at the intersection of Henry Clower Blvd/Oak Road and those at the intersection of Grayson Pkwy is approximately 1:6. As a surrogate to crash data, the PET data is expected to correlate with the crash data at some threshold PET value. The first set of PET data was collected at both intersections on October 4th, 2010 during off-peak hours, from 10 AM to Noon and again from 1 PM to 4 PM. In Figure 30 it may be seen that no significant difference in the PET data collected at the two intersections were captured. This is particularly true at the lower end of the distribution, which is thought to be correlated to crashes. To evaluate the consistency of the results, additional data were collected on April 7th, 2011 during the same time periods as the first data set. Though there is more divergence between the distributions of PET data collected at the two intersections in the second data set than the first, the distributions still significantly overlap at the lower tail of the distribution with PET values of 3 seconds or less (Figure 31).

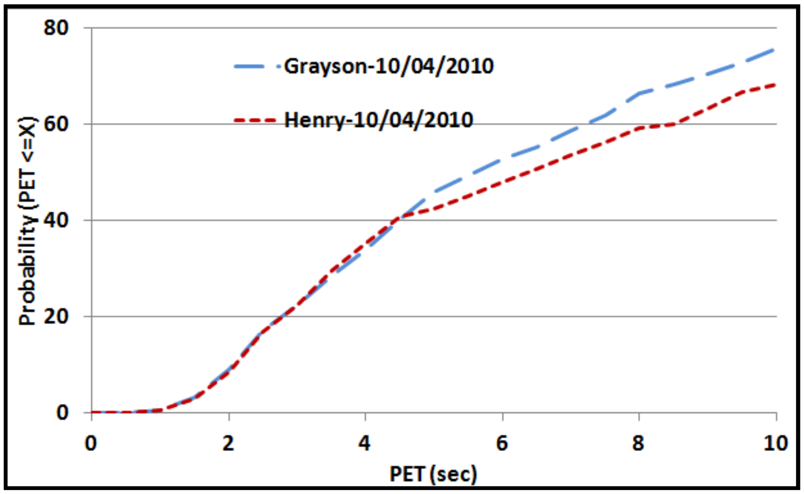


Figure 30 CDF plots of PET data collected on October 4th, 2010

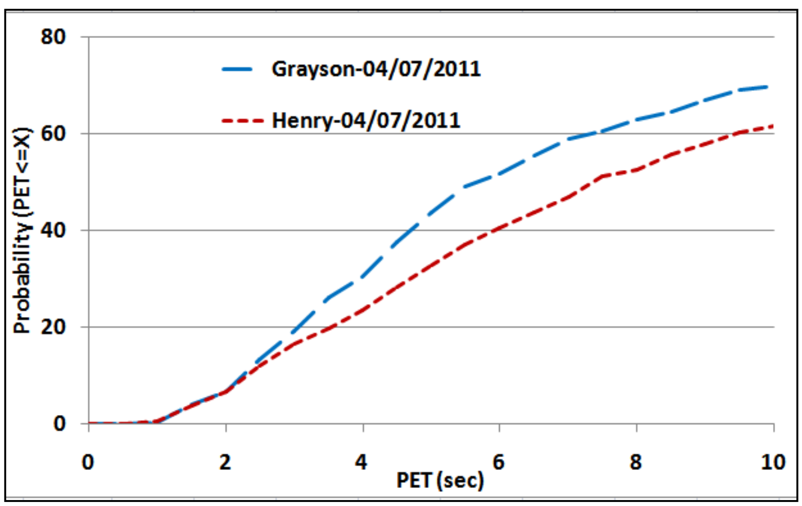


Figure 31 CDF plot of PET data collected on April 7th, 2011

Since the non-peak data did not show a significant difference in the CDF plots of the PET data collected from the two intersections, on May 6th, 2011, data was again collected at these two intersections, but during the PM peak hours from 4 PM to 7 PM. This data shows that the Henry Clower Blvd/Oak Rd intersection has higher proportion of low PET values than the Grayson Pkwy intersection, which is contrary to what might be expected from the crash data (Figure 32).

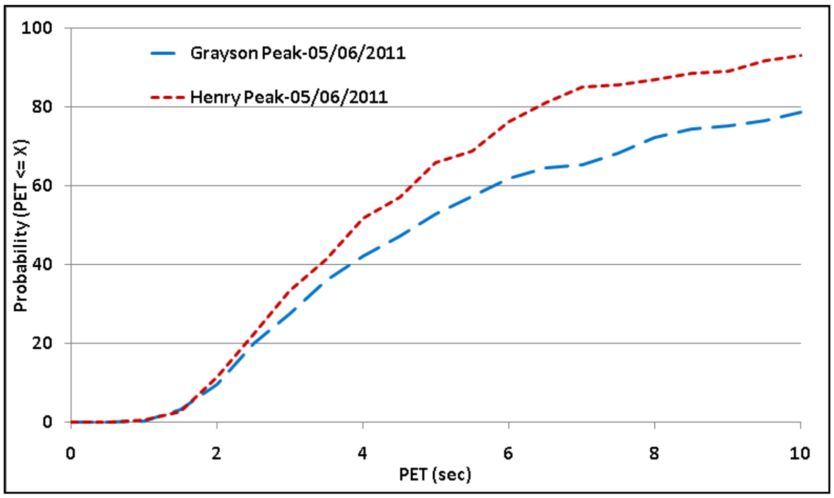


Figure 32 CDF plots of PET data on the May 6th, 2011

Thus far, the analysis has considered only the PET proportions at each intersection. However, it has been seen that the proportion of PETs below a threshold at the two intersections fails to sufficiently reflect the differences in crash data. Next, it was explored if the absolute number of PETs observed below a threshold value could be considered as representative of crash propensity (Figure 33 and Figure 34). From the non-peak data (Figure 33), it can be seen that the number of PETs 3 seconds or less is similar for the Grayson Pkwy intersection and Henry Clower Blvd/Oak Rd intersection. If we extend the threshold to 6 seconds, the Grayson Pkwy intersection had a slightly higher number of PETs than Henry Clower Blvd/Oak Rd. From the PM peak hour data, it can be seen that the number of PETs 3 seconds or less is higher for the Grayson Pkwy intersection than for Henry Clower Blvd/Oak Rd intersection. This observation matches the incident data trend (Figure 34). Thus, for this intersection pair, the absolute cumulative frequency count reflects the same pattern as seen from crash data, though not in the same magnitude. However, while the absolute cumulative frequency counts echo the pattern found in the crash data, it does not reflect the magnitude of the crash difference.

Grayson Pkwy-Non Peak					Henry Clower Blvd/Oak Rd-Non Peak			
Bin	Frequency	Cum.Fre.	Cum.Prob.		Bin	Frequency	Cum.Fre.	Cum.Prob.
0	0	0	0.00		0	0	0	0.00
0.5	0	0	0.00		0.5	0	0	0.00
1	2	2	0.33		1	3	3	0.47
1.5	20	22	3.66		1.5	19	22	3.43
2	24	46	7.65		2	25	47	7.32
2.5	43	89	14.81		2.5	41	88	13.71
3	34	123	20.47		3	32	120	18.69
3.5	40	163	27.12		3.5	30	150	23.36
4	28	191	31.78		4	28	178	27.73
4.5	41	232	38.60		4.5	33	211	32.87
5	36	268	44.59		5	22	233	36.29
5.5	27	295	49.08		5.5	23	256	39.88
6	19	314	52.25		6	22	278	43.30
6.5	19	333	55.41		6.5	19	297	46.26
7	20	353	58.74		7	20	317	49.38
7.5	14	367	61.06		7.5	23	340	52.96
8	19	386	64.23		8	13	353	54.98
8.5	11	397	66.06		8.5	15	368	57.32
9	13	410	68.22		9	15	383	59.66
9.5	14	424	70.55		9.5	18	401	62.46
10	10	434	72.21		10	10	411	64.02
More	167	601	100.00		More	231	642	100.00
	601					642		

Figure 33 Absolute frequency counts of the non-peak hour PET data

Grayson Peak					Henry Peak			
Bin	Frequency	Cum.Fre.	Cum.Prob.		Bin	Frequency	Cum.Fre.	Cum.Prob.
0	0	0	0.00		0	0	0	0.00
0.5	0	0	0.00		0.5	0	0	0.00
1	1	1	0.42		1	1	1	0.68
1.5	7	8	3.35		1.5	3	4	2.72
2	15	23	9.62		2	13	17	11.56
2.5	25	48	20.08		2.5	16	33	22.45
3	18	66	27.62		3	16	49	33.33
3.5	20	86	35.98		3.5	12	61	41.50
4	15	101	42.26		4	15	76	51.70
4.5	12	113	47.28		4.5	8	84	57.14
5	13	126	52.72		5	13	97	65.99
5.5	11	137	57.32		5.5	4	101	68.71
6	11	148	61.92		6	11	112	76.19
6.5	6	154	64.44		6.5	7	119	80.95
7	2	156	65.27		7	6	125	85.03
7.5	7	163	68.20		7.5	1	126	85.71
8	10	173	72.38		8	2	128	87.07
8.5	5	178	74.48		8.5	2	130	88.44
9	2	180	75.31		9	1	131	89.12
9.5	3	183	76.57		9.5	4	135	91.84
10	5	188	78.66		10	2	137	93.20
More	51	239	100.00		More	10	147	100.00
	239					147		

Figure 34 Absolute frequency counts of peak hour PET data

After the analysis of the data collected from the two intersections, it was determined that for the next set of additional intersections, the condition of both the intersections being on the same corridor could be relaxed. This would allow the team to choose a pair of intersections with a more significant difference in the crash history while still having similar geometry and traffic volumes. The additional intersections selected were Wieuca Rd at Roswell Rd in Fulton County (Figure 35) and Buford Hwy at Sugarloaf Pkwy in Gwinnett County (Figure 36).

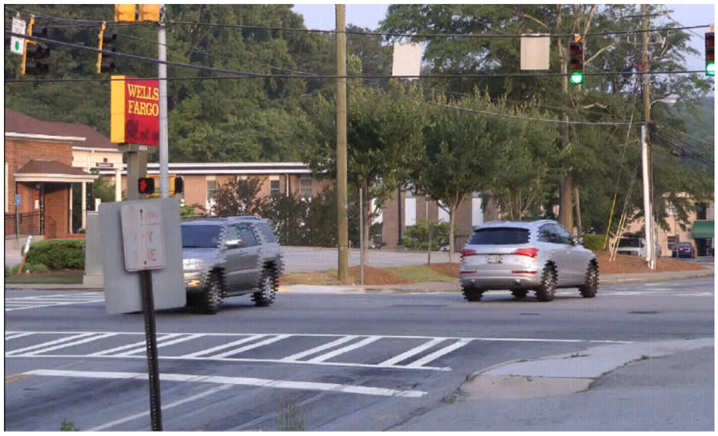


Figure 35 Intersection of Roswell Rd and Wieuca Rd

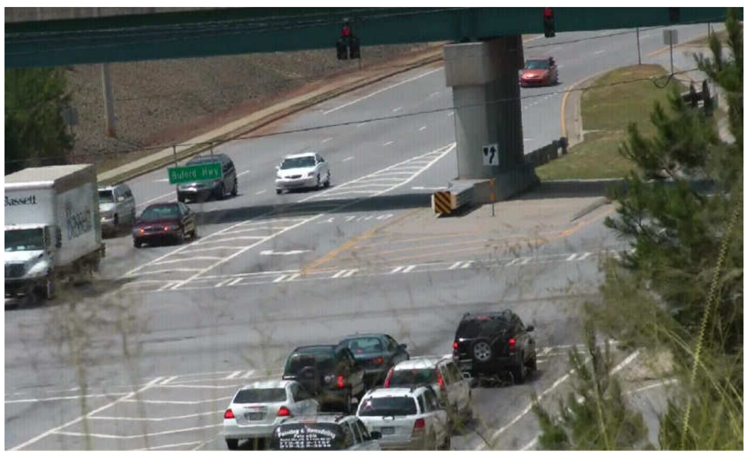


Figure 36 Intersection of Buford Hwy and Sugarloaf Pkwy

The intersection of Roswell Rd and Wieuca Rd had 123 left-turn opposing through crashes from the years 2000 to 2009. It ranks 3rd in the total number of left-turn opposing crashes at intersections in Georgia based on crash data aggregated over this time period. Therefore, it is an intersection which can be considered to have a high potential for crashes with respect to the crash type being considered. The intersection of Buford Hwy and Sugarloaf Pkwy had only seven left-turn opposing through crashes over the same 10 year period. The ratio of the total number of left-turn opposing through crashes at these intersections is approximately 20:1.

Video data at these intersections were collected during peak and non-peak hours. Data at the intersection of Roswell Rd and Wieuca Rd were collected on May 31st, 2011 from 7 AM to 12 Noon while data at the intersection of Buford Hwy and Sugarloaf Pkwy were collected on June 3rd, 2011 from 2 PM to 7 PM. The video data were later reduced to obtain PET data (Figure 37).

An investigation of the PET data collected at these two intersections shows that approximately 25% of PET data collected from the intersection of Roswell Rd and Wieuca Rd are less than or equal to 3 seconds whereas only 4% of PET data collected at the intersection of Buford Hwy and Sugarloaf Pkwy are less than or equal to 3 seconds. Data also shows that for a PET value of 1 second or less, the cumulative probability value for the intersection of Buford Hwy and Sugarloaf Pkwy is 0.202 while that for the intersection of Roswell Rd and Wieuca Rd is 2.72, which is approximately 14 times greater. As the PET value increases, this ratio decreases to approximately 5 and is never greater than the 14 found at a PET value of 1 second. It is also observed that there are no measured PET values below 0.5 seconds at either intersection.

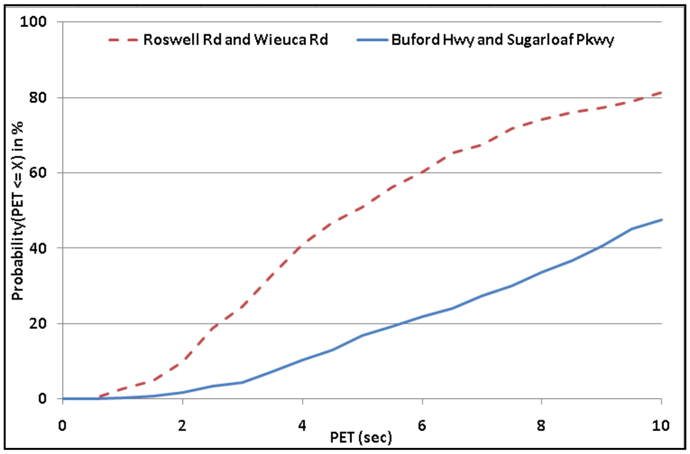


Figure 37 CDF plots of PET data collected at the second pair of intersections

Similarly, as argued in the first set of intersections analyzes, the absolute number of PETs observed below a threshold value could also be considered as representative of crash propensity. The intersection of Roswell Rd and Wieuca Rd had 72 interactions which had a PET value of 3 seconds or less whereas the intersection of Buford Hwy and Sugarloaf Pkwy had 22 interactions in this PET range. Therefore, the absolute frequency of PETs below a threshold of 3 seconds shows a ratio of 3.27. Figure 38 shows ratio for each threshold value.

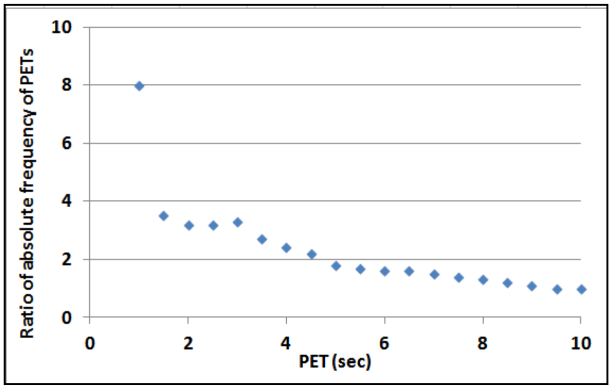


Figure 38 Ratio of absolute frequency counts between PET data of the two intersections

For a PET value of 1 second or less, the intersection of Roswell Rd and Wieuca Rd has 8 times more observations than those from the intersection of Buford Hwy and Sugarloaf Pkwy. As seen in Figure 38 as the threshold value increases, this ratio factor decreases.

Conclusions

The first pair of intersections studied (Grayson Pkwy and Henry Clower Blvd/Oak Rd, both with GA 10) has an incident ratio of approximately 6:1 for the left-turn opposing through crashes which occurred from the year 2000 to 2009 while the second pair of intersections (Roswell Rd with Wieuca Rd and Buford Hwy with Sugarloaf Pkwy) has an incident ratio of approximately 20:1 for the same crash type and time period. The analysis of the PET data collected at these intersections showed that the Grayson Pkwy and Henry Clower Blvd/Oak Rd intersections did not show any significant difference in the PET data distribution. The intersections of the Roswell Rd with Wieuca Rd, and Buford Hwy with Sugarloaf Pkwy, on the other hand, showed significant differences in the PET data collected. Therefore, it can be hypothesized that PET, as a surrogate measure of safety, might be sensitive to the difference in safety between the intersections. It is possible that PET may act as an effective surrogate for comparing safety of two intersections having high differences in crashes while it may not capture the difference between intersections which are moderately different in safety or that significantly more data is needed to capture such differences. Thus, while for the given intersections, PET has demonstrated the potential to distinguish between highly significant safety differences. It remains uncertain what level of safety difference may be identified.

Additional research will be needed before PET can be viewed as a robust quantitative surrogate measure for estimating intersection safety.

Implementation

Given the results of the current study, PET data is likely most suited for use in the before versus after evaluation of safety treatments where a significant safety issue is being addressed. In this situation an identified difference in PET value is likely indicative of a safety improvement. Failure to find a PET difference indicates that a safety improvement may exist; however, the PET data is not able to reflect this difference or no safety improvement has been obtained.

To allow for successful use of PET data by the Georgia Department of Transportation, it is recommended that for safety treatments that address potential encroachment time issues PET studies be completed before and after treatment implementation. Traditional incident based studies should still be completed after sufficient time has elapsed at each treatment site to verify the PET findings. The traditional incident based analysis will not only provide a direct measure of safety improvements but allow for continued development of PET analysis. Of particular interest will be the fidelity of PET data to the ratio of incidents (particularly in studies of before versus after conditions) as well as investigating the quantity of PET data required for analysis. As additional data becomes available, the reliability of PET data will become better known and PET analysis will be able to be targeted at locations where it may prove most informative.

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