FINAL REPORT

FEASIBILITY OF APPLYING THE GLOBAL POSITIONING SYSTEM TO LOCATE MOTOR VEHICLE CRASHES

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ABSTRACT

Countermeasures for motor vehicle crashes are often determined after extensive data analysis of the crash history of a roadway segment. An important factor that drives the value of this analysis is the accuracy, or precision, with which the crash is located. Yet this location is only as accurate as the estimate of the police officer. In light of this, many have suggested that global positioning system (GPS) technology has the potential to increase data accuracy and decrease the time spent recording crash location data.

Over 10 months, the locations of 34 crashes were determined using both the conventional method and a hand-held GPS receiver. The two methods were compared in terms of timeliness and precision. The benefits of any improved precision using the GPS were assessed through querying crash data analysts at the local level as to how the improved precision affected their consideration of potential crash countermeasures for five crashes selected from the sample.

At the scene of the crash, the use of GPS receivers added up to an average of 10 extra minutes per crash, depending on how *crash location* was defined. There was an average disparity of 130 ft (39 m) between the location as determined with the GPS and conventional methods, presuming the GPS precision given in the literature is within 7 ft (2 m). However, although both the literature and survey responses revealed that greater precision will affect evaluation of crash countermeasures in some instances, many of the errors cited in conventional crash location methods arise from human error rather than precision. The authors provide recommendations for defining *crash location* uniformly, limitations of the methodology employed in this effort, and the types of countermeasures that may or may not benefit from improved precision.

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INTRODUCTION

State and local agencies throughout Virginia spend substantial resources to improve highway safety. Crash countermeasures are often determined after extensive data analysis, a component of which is the physical location of the crash. Consequently, an important factor that drives the value of this analysis is the accuracy or precision with which the crash is located.

Global positioning system (GPS) technology provides an accurate means of capturing location data. Using a system of orbiting satellites, transmitters, and computers, GPS can determine latitude, longitude, and altitude measurements to a high degree of precision.[1] Raw error may range from 60 to 600 ft (18 to 180 m), but with correction algorithms, known as differential correction, one may obtain error values of less than 3 ft (3 m).[1,2,3]

Almost 10 years ago, in a discussion of the feasibility of GPS as a technology for collecting crash location data, Sabra et al. stated: "In the future, accurate positions will be a cheap, readily available commodity."[4] Although GPS technology has advanced, the fundamental questions of whether its benefits outweigh its costs and how to use it if they do remain.

PROBLEM STATEMENT

Crash location information is only as accurate as the police officer's estimate. Although fatal crashes receive substantial scrutiny, there is a limited amount of time to obtain precise location measurements for most crashes, especially when there is a need to clear the scene and move traffic. It has been suggested that the use of GPS technology may have the potential to substantially improve the accuracy and timeliness of determining crash location. The benefits and disadvantages of such use, however, have not been well documented, although efforts in this area are underway by the Federal Highway Administration (FHWA). Consequently, there may be practical lessons that remain to be learned through hands-on experimentation. Initially, these lessons include determining (1) the accuracy of GPS when compared to methods presently used for collecting crash location data, (2) the time saved or lost at the crash scene by using GPS, (3) the feasibility of developing uniform procedures for collecting GPS data, and (4) the utility of more precise locations for crash data analysts at the local level.

POTENTIAL BENEFITS

The procurement costs of GPS processing are relatively small; low-end GPS receivers, capable of differential correction, could be acquired for as little as $3,000 at the outset of this effort in 1996. The personnel costs, however, may be more substantial, depending on how much time is devoted to training and differential correction. This research project sought to learn lessons that would help an agency minimize such costs and evaluate the limitations and benefits of GPS. Specifically, law enforcement agencies that collect crash data may profit from either learning how to apply this technology or finding out its limitations, and other users of crash data may benefit from more precise crash locations.

METHODS

The following tasks were employed to perform this study.

1. Determine a working definition for the crash location. Reports for fatal motor vehicle crashes in Albemarle County during 1993-95 were reviewed. Although fatal crashes are not the focus of the GPS effort, they were selected for study, for this particular task only, because the events that occur therein are described in much more detail than for non-fatal crashes. For each crash, possible points of interest to analysts as to crash location were identified, as outlined in Appendix F. In addition, the appropriate literature was consulted as to what is defined as the crash location.

2. Develop draft GPS data collection procedures. A draft survey was developed to have consistent procedures for collecting GPS information and conventional location information. This survey was provided to the Albemarle County Police Department for comments and modified accordingly. Because of the duties of the officer at the scene of the crash, it was essential that the survey procedure be as short as possible. The survey collected five categories of information for each crash pertaining to the cost of data collection and the level of precision of the location measurement method:

- definition of the crash as a single point only
- definition of the crash as three points: first harmful event, first point of impact, final rest
- determination of the location by line of sight or with an odometer
- determination of the location with a wheel

- determination of the location with a GPS receiver.

For this project, the emphasis was not on measuring the precision of the GPS receiver; this has been well documented by other efforts, is relatively well known, and was observed in a couple of simple tests we conducted. Instead, the emphasis was on learning how other methods of determining the location compare both in terms of precision and cost to using the GPS receiver.

3. Collect pilot crash data with the officers. Over two 9-hour shifts, an employee of the Virginia Transportation Research Council (VTRC) accompanied two officers in their normal duties. The shifts lasted from 3:30 P.M. to 1:00 A.M., which allowed observation of data gathering procedures during day and night. Information such as how the officer would normally have determined the crash location, challenges to using the GPS receiver at the sight of crash, and the feasibility of the crash location definitions was collected. Lessons learned were used to modify the survey form, and the revised survey form is shown in Appendix A.

4. Obtain a larger set of crash data from the officers. The Albemarle County Police Department then collected the data elements outlined in task 3, without a VTRC member being present, for selected reportable motor vehicle crashes. One Trimble GeoExplorer receiver was loaned to the police department by VTRC, and the department purchased a similar receiver. Approximately every 2 weeks, or longer if no crashes were recorded, a VTRC employee visited the police department, picked up the two GPS receivers, downloaded the receiver data to a PC at VTRC, downloaded correctional data from a Trimble base station via modem, differentially corrected the raw data points, averaged the corrected data, displayed the final points, computed the distances between the three crash points defining the crash location as measured by the GPS receiver and by the officer, recorded the police survey results, purged the old crash data from the receivers, and then returned the receivers the following morning to the department. Based on the results and discussions with the department, additional modifications were made to the data collection procedures. The differential correction was done subsequent to the data collection, hence the term *post processing* is often used; however, it is possible to perform this step in real time.

5. Analyze the location methods with respect to accuracy and timeliness. From June 1996 until March 1997, 34 crashes were investigated; the first 2 were used for training purposes and were not included in the analysis. The sample size of the remaining 32 crashes was not chosen at the beginning of the study but instead was the number of crashes that could be obtained over the 10-month period within the personnel constraints of the police department. In fact, it is estimated that for a similar period in 1994, about 1,500 reportable crashes would have occurred in Albemarle County.[5] Finally, although at least two of the sampled crashes did involve a fatality, fatal crashes were not the focus of the investigation.

Thus for 32 crashes, the difference between the conventional method of locating a crash, the crash location as measured with a wheel, and the GPS measurement was computed. In addition, the time each method required and any unique problems associated with each method were noted.

6. *Prepare a representative sample of crashes for examination by local authorities*. A review of the relevant literature suggested many situations where it is possible that variations in the precision of the method for locating crashes will substantially affect the analysis of countermeasures. A second question, however, is whether any variations in this precision affect local analysts' immediate consideration of countermeasures. Therefore, once the entire set of crashes was obtained, five were selected such that urban and rural locations were represented. The sample size of five crashes was broad enough to represent some important characteristics but small enough such that the survey could be completed in a reasonable amount of time.

The five crash reports were then shown to crash data analysts and/or GPS personnel within the appropriate law enforcement agencies (e.g., the Albemarle County Police Department, the City of Charlottesville Police Department, and the Virginia State Police), the appropriate functional units of the Virginia Department of Transportation (VDOT) (e.g., residency, district, and central office personnel), the Department of Motor Vehicles, and the appropriate local governments (e.g., the Thomas Jefferson Planning District Commission and the City of Charlottesville Traffic Engineering Department). We specifically targeted persons who either were familiar with the geographical area or had expressed a strong interest in this type of research. Representatives were asked to evaluate any tradeoffs between accuracy and the time associated with each data collection method. For example, knowing that the point where a vehicle first ran off the road was not where the vehicle finally stopped might be "nice," but representatives were asked whether such additional information affected their consideration of potential countermeasures. Because of the specific nature of the survey, its design is detailed in the Results section of this report.

Steps were taken to increase the response rate: persons were contacted prior to receiving the survey and again (multiple times if necessary) when the initial survey deadline had passed. If necessary, additional copies were mailed, and in one instance, the completed survey was picked up directly. By listing each respondent's name at the top of the survey, we sought to convey the message that each person's views were important, as they each represented various market segments of the "customers" of crash data.

RESULTS AND DISCUSSION

Definition of Crash Location

How Crashes Are Currently Located

The current practice for locating crashes is for the officer to designate on the official motor vehicle crash report form (FR-300P) the distance of the crash from an intersection or appropriate landmark. Using both this information and a crash diagram, data entry operators then determine a single point as the crash location with respect to their computer's particular referencing system. For example, VDOT has a link-node referencing system; thus the operator finds a node closest to the crash and then computes an offset that gives the distance between the crash and the node. Hence, for nonfatal crashes, it is customary to define a single point as the crash location.

What Constitutes the Crash Location

There are at least three sources of error that occur when one states that a crash is located at a specific spot. The first type of error concerns the nature of the crash, and the relevant question is "what do we mean by the crash location?" For example, do we mean the place where (1) the vehicle began to deviate from its normal course of travel; (2) the vehicle left the roadway; (3) the vehicle struck another vehicle, fixed object, or pedestrian; or (4) the vehicle stopped? There may also be multiple events (e.g., the vehicle skids, leaves the roadway, returns to the roadway, and then comes to rest on the shoulder).

Historically, this has not been a significant issue for nonfatal crashes because of the presence of a second type of error, which is the tolerance of the measuring device, whether that device be an odometer, line of sight, or pacing. For many crashes, the distance between the multiple events may very well be less than the error associated with how the location is measured. For example, if all these events occur within 300 ft (90 m) of one another and the crash location is measured to the nearest 1/10 mi (158 m), it clearly does not matter which point is defined as the crash location. GPS, however, offers the opportunity to more precisely define each of these locations, which means that how the crash is defined may become relevant, depending on the nature of the analysis that is later performed.

Finally, a third type of error may be characterized as "how accurate is the crash location in relation to other significant features?" In other words, if we all agree that the point of impact is the crash location, the subsequent causal analysis of the crash can be biased if the point of impact is recorded as being closer or further from relevant features than it actually is. In the case where a pedestrian is struck, should the crash location be in error by, say, 200 ft (60 m), then the analyst might mistakenly believe that the pedestrian was in the intersection when he or she was not.

For some crashes, the orientation and number of vehicles involved in a crash can affect the location. As shown in Appendix F, the report of a two-vehicle crash that occurred on May 20, 1994, shows that the location may vary by about 80 ft (24 m) depending on which vehicle and which portion of the vehicle is defined as the crash "location." For crashes with a single automobile, though, the lower bound of error seems to be the length of a single vehicle (e.g., about 15 ft [4.5 m]) under the assumption that measuring a crash location at one wheel or another will not significantly affect analyses of aggregate causal factors.

Finally, an examination of the fatal crashes in Albemarle County for 1993-95 suggested several possibilities for defining a crash location, where the most consistent point appears to be either the point of impact or the final resting place of vehicle 1. Yet, in some cases, one could easily lose some information if these events transpired over a long distance, e.g., a feature caused a vehicle to leave the roadway at point *x,* but the vehicle did not stop until several hundred feet later. Therefore, a procedure where multiple events over a longer distance could be captured by a "beginning" and an "ending" point has merit. Since consistency in reporting procedures is essential, however, these multiple points would need to be recorded for each crash, even if the points were very close.

Relevant Literature for Defining the Crash Location

A Virginia crash coding manual recommends that crashes be recorded to the nearest one-hundredth of a mile (approximately 50 ft [15 m]) whether the point of reference is a milepost marker, intersection, or other type of landmark.[6] Interestingly, the example shown in the manual raises a question about what the crash location should be: the point where one vehicle leaves the roadway, the point where it returns to the roadway, the point where it strikes another vehicle, or the point at which a pedestrian is struck and killed? The manual uses the point of impact of the two vehicles as the crash location.

The National Safety Council bases many of its classification methods on the "first harmful event."[7] For example, a crash may be categorized as an intersection crash, a driveway access crash, or an interchange crash depending on where the damage, injury, or death first occurs. From this, therefore, one would expect to define a crash location only when a collision occurred, not necessarily where the driver began to deviate from the normal path of travel, unless that, too, could be described as a "harmful event." The same document, however, explains that a traffic crash may be defined as either a harmful event or an "unstabilized situation." Conceivably, then, a person losing control of his or her vehicle for any reason (e.g., a wheel drops off the side of the road and the driver's response is to overcorrect) could in itself be construed as a crash or harmful event. A National Highway Traffic Safety Administration (NHTSA) representative explained that NHTSA uses the location of the first harmful event as the definition of the motor vehicle crash location and recommends that other states also use this definition.[8]

The American National Standards Institute (ANSI) defines several items that would be relevant to this question of crash location.[9] These include the location of the first harmful event or object, the location of the second harmful event or object, the most harmful event, and the relation to the roadway. There is no indication, however, of which point should be defined as *the* crash location given that multiple events occur.

Therefore, the following rationale was initially suggested: the points at which a traffic crash "began" and "ended" would be selected. A representative of the Albemarle County Police Department expressed an interest in knowing also where the first collision occurred. This would usually correspond to the ANSI standard of where the "first harmful event" occurs since the ANSI standard defines a harmful event as "an occurrence of injury or damage."[9] The standard then notes that one may describe a crash in terms of the type of first harmful event that occurs: eight types that are "collisions" correspond neatly with the "first point of impact," whereas two types that are "non collision" (overturn and jackknife) are simply places where a harmful event occurs.[9] In brief, therefore, it would appear that the "point of impact" is meant to be the "first harmful event," according to the ANSI standard.

Thus, three points were initially suggested for defining the crash location: a "beginning" point, a "first impact" point, and an "ending" point. The police department pointed out that the definition of *first harmful event* should include not only collisions but also cases where the driver deviated from the normal course of travel, such as swerving to avoid an impact or braking suddenly. Therefore, the definitions of the three crash locations were changed to *first harmful event, first point of impact,* and *final rest,* respectively.

Information From Ongoing or Previous Studies

FHWA has been working with four jurisdictions to investigate the use of GPS and laptop computers to record crash information. Conversations with some of the participants from the jurisdictions in June 1996 had suggested that the crash location was usually defined as where the officer's vehicle was parked, and a draft report made available to us by FHWA appears to use only one point that would define the crash location.[10]

A 1996 literature search using the Dialog database showed one potential GPS and crash data effort, which was started in 1995 but was terminated. A California Department of Transportation representative, though, did mention an effort in the Southern California area where police cruisers would be outfitted with GPS receivers to identify their locations and assist in routing police response to incidents.[11] In addition, an Australian pilot test compared data entry times for a GIS-based method and a manual data entry method. For that test, it appears that a single point was defined as the crash location.[12]

A third source provided valuable insight into the feasibility of requiring identification at the scene of three points. An FHWA effort had compared a quality-controlled database maintained by NHTSA to select paper reports completed at the scene of the crash. Although there were few discrepancies among some aspects of the reporting, the study also showed that some of the variables had high discrepancy rates, such as the vehicle identification number and the manner of collision. One of the variables tested, the "first harmful event," was listed as "varying by jurisdiction" in terms of how often the paper report differed from the central database for that variable. Thus, although this variable is not the most problematic, it suggests that there could be a training cost associated with routinely documenting the three aspects of a crash location identified here.[13]

Lessons Learned From Individual Crashes

Over two 9-hour periods (July 15 and July 18), from approximately 3:30 P.M. until 1:00 A.M., a VTRC employee rode with an officer who was assigned a specific portion of the county to patrol. For those two shifts, the officer's primary focus was traffic crashes, although a number of other duties were required. During the first shift, two incidents were investigated: one property-damage-only crash that had occurred slightly before 4 P.M. and one fatal crash that occurred around 11:30 P.M. These incidents, along with observations made by the officers at other crash sites, provided important information about how to proceed.

Data Collection Procedures

These two incidents illuminated problems with the survey that had been employed. First, the original concept of identifying three points to define the crash location could be confusing in some instances, since the first incident involved three distinct collisions, each collision involving two vehicles. Therefore, for this particular case, the solution was that the incident was composed of three distinct crashes, as three separate FR-300P crash report forms were completed. Clarifying information was added to the survey such that one form should be filled out for each FR-300P. In addition, the crash location definitions were revised.

Second, for the former incident, it was not safe to stand in the intersection where the first harmful event had occurred, so an offset was needed between the location of the receiver and the location of the actual crash. The same issue arose later for another crash at a different site. Fortunately, the error associated with standing to the edge of the road was relatively small, although this offset of one lane width could become significant for other types of crashes depending on the roadway conditions.

Tracking the Satellites with the GPS Receiver

The nighttime incident had occurred in a heavily wooded valley, which resulted in the receiver needing about 25 min to record a single point. At another site when we were not present, an officer remarked that power lines may have contributed to what appeared to be a longer than usual delay in the receiver being able to track the satellites. Hence, it became clear that the time it takes to obtain a reading from satellites could vary greatly depending on the location, even within a single county.

At this point, it also became necessary to adjust one of the receivers, which may have explained the perceived problem with the power lines. The officer had noted that one receiver was taking an extraordinary amount of time to obtain sufficient satellite readings to determine the location, and examination of the receiver the following morning revealed that it was taking longer than had been the case a few months earlier. A few days later, we found that the receiver was taking approximately half an hour to record the location. Two steps were necessary to rectify the situation: first, the factory defaults were reset, and second, the SNR and PDOP masks were modified.

In addition, it was suggested that two options that should be considered in the future were to use an external antenna and activate the receiver at all times, or at least as soon as one arrived at the site.[14] This would allow the receiver to track the satellites at all times; in the instance of the nighttime incident, it should have taken less time to simply begin recording a position rather than having to first locate the satellites. These two options were not actively pursued for this project but would be worthy of consideration in future efforts.

Finally, in a separate effort, two researchers encountered an unexpected difficulty with collecting data: the strobe lights atop VDOT vehicles were interfering with the ability of GPS receivers to track satellite data.[15] In that instance, the researchers were using a GPS unit with an antenna mounted directly on the vehicle, whereas we had used GPS units where the antenna was only inside the receiver. These researchers suggested that the police sirens could have a similar effect on the hand-held GPS units. Placing the GPS unit directly on top of the police cruiser with the lights in operation did not appear to affect its ability to obtain a position reading from the satellites (although the authors did not compare the resultant precision with and without the sirens). This test should be conducted again, however, if the decision is ever made to use GPS receivers that employ an external antenna attached to the police vehicle or when an agency first experiments with GPS, as the siren technology can vary (e.g., this particular law enforcement agency had two types of sirens).

Changes to the Data Dictionary

Early in the data collection process, it became clear that a more flexible mechanism for recording crash identifying information was needed. Initially, the GPS receiver had been programmed with a data dictionary where the officer would enter his or her name, the date and time of the crash, and labels for the three points defining the crash location, in that order. In several situations, however, the officers needed the flexibility to enter this information in a variety of formats; in some instances, for example, it would be easier to record the point of final rest before recording the first harmful event. Although it is technically possible to enter the data dictionary information in any order, it appeared conceptually easier to record each of the three components of the crash location as a separate GPS file, thereby eliminating some of the additional data dictionary steps.

At the time, we envisioned a second reason for using a separate file for each of the three crash location spots: the differential correction procedure, which was done at the time the data were downloaded from the receiver to the PC, is sensitive to the hour in which the data are originally collected. Although one may bypass the problem of data being collected over two hourly periods (e.g., from 11:55 to 12:05) by combining the base station files and then performing the differential correction procedure, it was one less step to keep readings within the same hourly period as much as possible. However, software upgrades may make this latter issue a moot point, and it was later pointed out that there was a much easier way to overcome this problem.

Post Processing the GPS Data

For crash 12 shown in Appendix B, the crash data did span two time periods. Initially, we corrected the points before and after the hour as two separate files and then combined the results, but the "averaged" file gave two distinct locations, which were apart by 16 ft (4.8 m), or approximately one car length. At the conclusion of the effort, however, a reviewer pointed out that one should instead combine the base station data and then post process the data. Doing this showed the "true" location to be on a line between the two initial locations, where it was 9.9 ft (3 m) from one and 5.9 ft (1.8 m) from the other. Hence, our decision to post process these data as two separate files was erroneous, but since this applied to only two of the crashes and since the disparity was not large, this should not have affected the results significantly.

Post processing the data with a base station further away did not appear to cause substantial problems for these particular types of applications. The potential problem emerged when files were collected on Sunday evening around midnight, a time when the Charlottesville area base station was not collecting satellite data. For post processing, it was, therefore, necessary to use data from a base station in Raleigh, North Carolina. Later, a comparison of one data point showed that there was an 1.8-ft (0.54-m) difference in the average location if one used the Charlottesville base station rather than the Raleigh base station. Finally, the base station differential correction files were available for a limited time, so attempts were made to download the necessary base station data every couple of weeks.

Possible Training Issues

The police survey results showed fewer anomalies after the first eight crashes. This may be due in part to the more flexible data collection procedure previously described, but it may also be due to the way in which some of the GPS data were collected. In some cases, a single officer obtained the data for several crashes that had occurred over the past week. Thus, it may be much easier to concentrate on these tasks when one person can do several at once. On the other hand, this may have been due to greater experience being obtained by the officers.

Further Study of a Single Crash

Much later in the project, a rural crash was investigated in greater detail because of problems encountered with the GPS receiver. Although the technical problems were resolved, detailed examination of the site yielded insights. A single vehicle had run off a secondary road, struck a mailbox, and then a tree, and the officer recorded these points as points A, B, and C, respectively. (See the figure in Appendix D, crash 2.) The distances AC, AB, and BC as measured by the officer, and then as measured by us with a wheel about 1 week later, were fairly close, with the distances being 200 ft (60 m) vs. 248 ft (74 m), 100 ft (30 m) vs. 165 ft (50 m), and 100 ft (30 m) vs. 83 ft (25 m). Making the measurements with the wheel took us approximately 3.5 min, whereas using the GPS receiver for all three locations took about 13 min.

Most telling, though, there were important details at the crash site that might be of interest to future analysts. The foreslope changes substantially from where the vehicle first ran off the road to where the trees were located 165 ft (50 m) away. The tire marks suggested that the vehicle came back very close to the roadway after running off it, especially in the area of the mailbox. Finally, the crash scene on the FR-300P is indicated to be 0.2 mi (1056 ft or 317 m) from the nearest intersection. Wheeling off this measurement showed that the crash scene was 1,400 ft (420 m), 1,565 ft (470 m), or 1,647 ft (494 m) from this intersection, depending on whether the first harmful event, first point of impact, or final rest was chosen as the crash location. Although these values are relatively close to 0.2 mi (1,056 ft or 317 m), their disparity could become relevant if one wanted to use geocoded roadway features in conjunction with the crash location.

(The term *foreslope* is used here to describe the connection between the edge of the shoulder farthest from the travel lane and natural ground. Yet, there was no directly observable backslope at the site. One individual pointed out that it would be more appropriate to use the term *fillslope* since the distinguishing feature is that the roadway is above the natural surface.)

Analysis of Crash Location Methods With Respect to Accuracy and Cost

Sample Size

After approximately 9 months, 34 crashes had been recorded using the two hand-held GPS receivers, 32 of which were suitable for further analysis. This sample size was large enough to give a flavor of what types of crashes would be suitable for querying crash data analysts and gaining an understanding of the data collection issues not envisioned previously. On the other hand, one could argue that to achieve a measure of statistical significance, a larger data set would be required. The issue for which that is most important, though, is the difference between the crash locations as measured by the officer and as recorded by the receiver. Approximately half of the crashes were investigated by two officers at two times: first, the officer without the receiver would investigate the crash as normally dictated by law, and later an officer who specialized in GPS data collection would take GPS measurements. Although this second officer could certainly take GPS readings at the appropriate points by reading the crash diagram, the second officer would sometimes not be able to indicate the distance of the crash from the appropriate landmark. Thus, the emphasis was on understanding the differences for individual crashes; to increase the statistical significance, one would have had to insist on having a single officer collect all the crash data at the same time.

Accuracy and Timeliness Evaluations

There are a number of ways one can evaluate the significance of the disparity between the crash distance as measured by the officer and as measured by the GPS receiver. The "new" approach presented here was to determine each crash location as three distinct points (first harmful event, first point of impact, and final rest). Thus, for each crash, one can obtain two sets of measurements *between* each of the three points: one set of measurements recorded by the GPS receiver and one set as recorded by the officer. The average values for the differences in these measurements are shown in the first three rows of Table 1. Although 34 crashes were studied, 2 were excluded because they were pilot efforts at the beginning of the study, 1 was excluded because differential correction could not be performed, and 2 were excluded because the relevant portion of the survey form was not completed.

Table 1: Disparity Among Using Conventional Methods, GPS, or a Wheel

Distance	Average Difference Per Crash	Sample Size
First harmful event to final rest	37 ft (11 m)	29
First harmful event to first point of impact	32 ft (10 m)	29
First point of impact to final rest	16 ft (5 m)	29
Crash location to landmark	130 ft (39 m)	16

Each crash also had the location defined as a single point. The survey also allowed us to compare the distance between that single point and the appropriate landmark, as measured by the officer in the conventional manner that was recorded on the police report form and as "measured with a wheel." Unfortunately, some of the surveys were completed not by the investigating officer but by an officer who came to the crash scene several days later, and in other cases this portion was not completed. For those instances, this last computation could not be made, and hence, the sample size was reduced accordingly. The result of this comparison is shown in the last row of Table 1.

For those crashes that required a second officer, it is possible that additional error was introduced into the computations of the crash locations as defined as three points. In addition, a wheel may not have always been available. In light of these two limitations, the differences shown in Table 1 should be viewed as reflecting the disparity between types of location methods used for each crash rather than absolute statements of the inaccuracy of a single method. (See Appendices B and C for complete data for each crash.)

Table 2 summarizes the results of the disparity in time required to record the crash location depending on the method employed and whether one defined the crash location as a single point or three specific points: first harmful event, first point of impact, and final rest. Two distinctions are made regarding these tasks: to *determine* the crash location refers to figuring out where the crash should be located, whereas to *measure* the crash location refers to measuring the distance between that point and the appropriate landmark. Since some survey responses were not completed, the sample size was always less than 34 crashes; the sample size for each parameter is given in the table. Finally, the last column provides caveats that should be considered when looking at these responses overall.

Examination of these averages and the data for the individual crashes shown in Appendices B and C reveals several insights about how one should proceed with the analysis. *First*, the notion of "averages" with respect to the disparity between crash distance as measured by GPS or a wheel is somewhat misleading for this sample because of the different nature of each crash. For some that occurred near an intersection, for example, a small difference might be significant whereas for rural crashes a small difference might not be relevant. Thus, it is better to examine individual crashes and consider how the disparity between the distances could affect analysis. For example, the fifth crash in Appendix B, where the officer stated no wheel was available, shows that although a line of sight estimation gave the distance between the first harmful event and the point of final rest as being 150 ft (45 m), the GPS receivers after post processing suggested that this distance was twice as great (302 ft or 91 m).

Table 2: Time Comparisons of Crash Location Methods

Parameter	Average (min)	Sample Size	Limitations
Time to *determine* crash location as single point	2.5	29	Times are rounded
Time to *measure* crash location as single point in conventional manner	4.7	29	Includes several methods: line of sight, odometer, pacing, and for 2 cases, a wheel
Time to *measure* crash location as single point using wheel	1.6	27	Respondents may have reversed this with previous question; also, wheel was rarely available
Time to *determine* crash location as three separate points	5.9	25	May have included time required to determine crash location as single point
Time to *measure* crash location as three points with wheel	5.1	30	Includes 3 cases where survey indicated no wheel available
Time to *measure* crash location as three points with wheel	5.6	27	Wheel was likely not used in other instances (even if not noted on survey)
Time to *measure* crash location as three points using *GPS*	11.4	28	At least 1 instance resulted in officer not being able to finish task because GPS took too long

This notion is underscored by an examination of the distribution of distances. For example, the distances in the last row of Table 1 (130 ft or 39 m) are much larger than the others. This is not the result of a single crash where there was a large discrepancy. Instead, there were rural crashes where rounding the location to the nearest tenth of a mile, as estimated by line of sight, increased this average value substantially. On the other hand, the values shown in the preceding rows of Table 1 are substantially lower. When the officer was in the correct general area of the crash, mistakes tended to be on the order of tens, rather than hundreds, of feet. One may compute the standard deviation for each of the four data sets represented by Table 1; the result is that the standard deviation divided by the average value is about 1.5 times higher for the fourth row than for the others. Given that there were substantially fewer values for the fourth row, however, this is not a very useful comparison.

Second, one needs to keep in mind how well defined each of these points may be. Not only will there be imprecision with the GPS receiver (although differential correction of this value can reduce this error to less than a couple of meters), but the exact crash location can probably be defined no better than at least a car length (typically 15 ft or 4.5 m). That is, the point of final rest could vary by approximately 15 ft (4.5 m) simply depending on which end of the vehicle the officer uses to take the measurement. Hence, a disparity of less than 15 to 20 ft (4.5 to 6 m) should be viewed with caution. In other words, unless one is going to define which end of the vehicle will be measured and how the vehicle's orientation will affect that measurement, then differences of less than one vehicle length are probably not significant.

Third, the average distance between the crash location (when defined as a single point) and the appropriate landmark is different depending on whether a conventional method is used (e.g., line of sight, pacing, odometer) or this location is measured with a wheel. For several intersection-related crashes, this difference had a value of 16 ft (5 m) or less, and for several others, this difference grew to 100 ft (30 m) or more. Given that it is not unusual for crash records systems to give crashes to the nearest 0.01 mi (53 ft or 16 m), an average disparity of 130 ft (39 m) is striking, especially when one looks at the crashes where this disparity is substantially larger.

Fourth, without using GPS, there is a noticeable difference between the time it took to record a crash location as a single point and as three separate points. If one adds the time it takes first to determine the location and second to measure the location, then recording all the events of the crash as a single point requires, on average, between 4 and 7 min. Recording the first harmful event, point of first impact, and final rest requires, on average, 11 to 12 min. If one uses a GPS receiver for all three points, however, the total time (determination plus measurement) jumps to approximately 17 min on average. Admittedly, this figure by itself is not very meaningful; it needs to be compared to the time required when GPS is not used. Given that officers have several duties at the crash scene, this increase in time is substantial. The officers also noted that it took longer using GPS to record the first point than it took to record either of the other two points; this is reasonable since the receiver has to begin tracking satellites after being turned off and moved to a new location. The delay does not come from operating the equipment but rather from waiting for the receiver to obtain an accurate reading from the satellites.

The time to post process the GPS data (or differentially correct it in real time) is not included in the 17 min. Steps such as downloading the correctional data via modem, downloading the data from the receiver to the PC, differentially correcting the raw data points, averaging the appropriate corrected data, displaying the data, measuring the appropriate distances, making appropriate corrections, and initially recording the additional information took approximately 20 min per crash. Later, our use of batch programming substantially reduced the duration of this process, and it is likely the duration could be shortened further if done on a larger scale. Even if data were not corrected in real time, for example, the task of downloading corrective data for post processing could be automated fairly easily.

Fifth, even though only a few officers from a single law enforcement agency participated in this study, there was variation in how the crash location was recorded depending on the surrounding area. Responses included pacing, the use of an odometer, line of sight estimation, and the use of a wheel. Generally, these methods require less time than GPS but are also less precise (except in the case where a wheel could be used to provide offset from a GPS location). The next question is: In what situations, if any, would the extra precision offered by GPS justify its cost?

What Differences in the Precision of Crash Location Signify for Local Efforts

Two areas of concern regarding the precision of crash locations are the impacts on findings resulting from statewide or national studies and the impacts on countermeasures considered by the local analyst. Although the former are often of a longer-term nature, the latter comprise issues that can be addressed almost immediately, whether as part of a safety improvement program, a before-and-after study, or an identification of potentially hazardous locations. To address this local emphasis, a survey for crash data analysts was composed.

Survey Design

The survey was designed with three key components in mind. First, the goal of the survey was to answer the following question: Does improved precision for locating crashes yield a better understanding of what types of countermeasures would be effective? Respondents compared, for each crash, at least two sets of measurements: one obtained in the conventional manner (usually line of sight) and one "measured" in a more precise manner using the GPS receiver. Second, it was important not to bias the respondents in favor of a particular technology; hence, they were simply told whether a distance had been "visually estimated" or "measured." Third, the survey focused on real crashes rather than hypothetical scenarios. For this effort, however, we decided to use real crashes with two sets of distances (real versus estimated) to keep the survey conceptually simple. The only exception is the second question for crash 4, where the one estimated distance was 0.2 mi (1,056 ft or 317 m) but no other distance was measured; in that case, we used distances of 1,000 and 1,200 ft (300 to 360 m) to see the impact of being off by 200 ft (60 m) in that situation.

An alternative, as pointed out by one reviewer, would have been to select a true distance and then form concentric rings of error distances and ask analysts at which distance the error would induce them to change their evaluation of countermeasures. A second option would have been to select a particular location, wait until several crashes had occurred at that location, and then ask analysts to compare the impacts of measured versus estimated distances. A complication that would result, though, is that precision would vary by location type. Intuitively, for example, we know that an intersection-related crash may very likely have more precise measurements because of the greater availability of landmarks than a rural crash location. To compensate for this, it would be desirable to have a larger sample of crashes where one could give a statistical measure of how the precision of the location will be affected by crash location and other relevant variables. In spite of these complications, however, both of these alternatives appear worthwhile for future study.

Five of the 34 crashes were selected, and for each crash, users were presented with four questions. For each crash, the first question asked users to briefly identify what types of countermeasures they would consider if multiple crashes of a similar nature had occurred. The remaining three questions asked users whether a more precise distance measurement than that taken by line of sight would be helpful in assessing the utility of these countermeasures. These questions also concerned whether knowing the crash location in terms of first harmful event (point A), first point of impact (point B), and point of final rest (point C) was beneficial as compared to simply knowing a single point that represents all three crash locations. The last page of the survey gave users a chance to offer free response. This survey of crash data analysts is shown in Appendix D.

Survey Responses

All of the functional units responded to the survey, although in some cases, two or more persons from the same agency or functional unit sent one response that represented their composite views.

As may be seen in Appendix D, each additional piece of information that follows the crash diagram and description is followed by a YES/NO question. A YES means that the information does influence the respondent's consideration of potential crash countermeasures, whereas a NO means that the information does not. Table 3 lists the number of persons responding YES or NO for each question. When a respondent checked both YES and NO for a particular question, half a point was assigned to each. Not all respondents responded to all questions.

The countermeasures that fell into each of these two categories and the respondents' answers to the free response section are shown in Appendix E.

Table 3: Whether Additional Information Affected Identification of Potential Countermeasures

Additional Information for Each Crash	**No. YES**	**No. NO**
Crash 1		
Crash location 50 ft, not 150 ft, from landmark	10.5	5.5
Distance from A to C estimated as 30 ft	4.5	11.5
Distance from A to C measured as 49 ft	4.0	12.0
Crash 2		
Crash location 1647 ft, not 1056 ft, from landmark	11.5	5.5
Distances AB and BC estimated as 100 ft	6.0	11.0
Distances AB and BC measured as 165 and 83 ft, respectively	7.0	10.0
Crash 3		
Crash location 37 ft, not 50 ft, from landmark	3.0	13.0
Distance from A to B estimated as 11 ft	7.0	9.0
Distance from A to B measured as 42 ft	5.0	11.0
Crash 4		
Crash location 1200 ft, not 1000 ft, from landmark	7.0	9.0
Distance from A to B estimated as 60 ft	8.0	8.0
Distance from A to B measured as 138 ft	8.0	8.0
Crash 5		
Distance from A to C estimated as 123 ft	4.0	12.0
Distance from A to C measured as 115 ft	3.0	13.0
Knew only that crash occurred in vicinity of intersection	5.0	11.0

Discussion of Survey Results

We were surprised that, in some cases, the additional information did not influence countermeasures. For example, when a crash was said to be a certain distance from two intersecting routes, some persons viewed the intersection location information as being relevant to locating the crash for future reference, whereas others viewed it as useful only if the crash was influenced by the intersection. Although, of course, the latter case is relevant, the former can become applicable should these data ever be coded into a system of heterogeneous roadway segments.

It was not surprising that countermeasures varied (e.g., DUI enforcement versus improved skid resistance) because of the diverse pool of respondents. One would expect a traffic engineer and a law enforcement officer, for example, to recommend useful but different countermeasures. It was surprising, however, that some persons who identified the same countermeasure would be influenced differently by the additional information. In some cases, for example, the disparity between the visually estimated distance and the measured distance did not alter consideration of a warning sign, whereas some respondents pointed out that such information would affect their view of that countermeasure. Agreement was not based necessarily on profession. For example, for crash 3 shown in Table 3, two engineers and one law enforcement officer viewed the disparity between 37 and 50 ft (11.1 to 15 m) as being significant, whereas other engineers and officers did not.

Although the free response section mentioned errors that arise from both poor precision and poor accuracy, more responses seemed to concern the latter. Regarding the specific crashes, there was an even greater tendency for precision not to be as large a problem as accuracy. That is, a disparity of 100 ft (30 m) because of estimating, although influencing some respondents' evaluation of countermeasures, was not uniformly viewed as serious. Some respondents were not affected by the additional information from knowing the first harmful event, first point of impact, and point of final rest. Table 3 reinforces this view. In many cases, the additional information obtained from greater precision did not influence a majority of the respondents to reconsider their proposed countermeasures. As illustrated with the conclusion of Appendix E, many respondents recalled instances where mistakes were made in placing crashes due to human error, e.g., placing a crash on the wrong bridge, at the wrong road with a similar name, or at the wrong intersection.

Some did, however, identify instances where precision, in addition to accuracy, was essential. Several persons pointed out that for reconstruction purposes, good crash diagramming could be useful, and one individual noted that the distance from an intersection can be crucial for determining whether a crash was intersection related. As shown in Table 3, two of the cases where more than half of the respondents indicated that the extra information would affect their countermeasures were cases where the overall crash location, when defined as a single point, was off by a substantial amount. One intersection-related crash was marked as 50 ft (15 m), rather than 150 ft (45 m), away from an intersection, and one rural crash was coded as being approximately 500 ft (150 m) from the true location.

Two respondents articulated a sentiment that pervades other aspects of crash records processing: users and providers of crash data have a different focus. Clearly, then, if only one of these groups were to make the decision about how data should be collected, the other group could be penalized, with the outcome being either that too many resources are spent collecting unnecessary data or that essential data are not obtained.

What Differences in the Precision of Crash Location Signify for Statewide or National Efforts

Crash data are not only employed at the local level; they may be used as part of a much larger database to study the impacts of particular roadway, driver, or vehicle phenomena. For example, lane width, shoulder width, and various combinations thereof have definite safety impacts depending on the road type and volume of a particular segment.[16] It is, thus, of interest to examine a few studies to see how the precision of a crash location with respect to these characteristics may influence the determination of countermeasures.

Influence of Specific Roadside Features

One area where the precision of the crash location may affect countermeasure analysis is in how the crash is perceived to be influenced by roadway features. Consider, for example, the problem of fixed objects located near the edge of the travel lane. In the discussion of the formulation of a roadside encroachment model, one potential hazard under consideration is the placement of utility poles and their impact on crash risk.[17] From that study, it is computed that based on the size of the pole, the width of the vehicle, and the angle of departure, the pole is likely to constitute a hazard for a 34- or 63-ft (10 to 19 m) stretch of the roadway, depending on whether the crash results from a right-side or left-side departure. If one were interested in using crash reports to validate such data, one would expect that for crashes where a utility pole was involved, the precision of the location would be irrelevant. Yet for cases where a vehicle did not contact the pole but was in proximity, the precision of the crash location would be relevant unless the officer had noted the existence of a feature (the utility pole) that did not appear to influence the crash.

Another encroachment modeling effort outlined several variables that appeared useful within the model. Examples that intuitively might change frequently along a stretch of roadway were number of driveways per mile, paved shoulder width, stabilized shoulder width, and median sideslope.[18] On the other hand, these authors stated that underreporting of minor crashes for this model would not substantially affect the encroachment frequency.

Others have suggested that an impediment to developing inventory-based models (for quantifying the impacts of fixed objects on crashes) is the large amount of data required, especially with respect to locating all relevant features and objects.[19] Thus, more precise crash locating abilities, in their own right, would not solve this problem unless these more extensive roadway data were available.

Section and Spot Length Determination

The length of the roadway segment that can be analyzed is also affected by the precision with which crashes may be located. Deacon et al. suggested that not only may a crash scene be several hundred yards long, but the section length or spot length must be greater than the error associated with the crash location method.[20] The example given was that in 1975, several states, including Virginia, used spot lengths of 0.1 mi (158 m), with the authors recommending that lengths of 0.3 mi (475 m) be used. If one desires to use, say, 0.1 mi (158 m) as a spot length, then one needs a precision of at least 528 ft (158 m). Further, examination of a 1980s planning study showed that changes in characteristics such as pavement width or number of lanes for segments of roadway as small as 0.07 or 0.15 mi (111 to 238 m) may occur, with changes every 0.30 mi (475 m) not being uncommon.[21] For the former case, one would desire a precision of at least 0.07 mi or 370 ft (111 m).

Such small segments are not always unreasonable. One study mentioned the use of segments varying in size from as large as 18 km to as small as 100 m to capture a stretch of highway with similar geometric characteristics.[22] Presumably, the small end of the scale was used to accommodate changes in aspects such as median width, surface width, surface type, etc. A Washington State principal arterial study pointed out that to allow for changes to characteristics such as number of lanes, shoulder or roadway width, horizontal or vertical curve details, and “presence of a curb or retaining wall,” segments smaller than 400 m in length may be needed.[23] One suspects that changes in design characteristics may occur more frequently on other classes of roadways (e.g., secondary roads), suggesting that to capture all such changes, even smaller segments would need to be considered.

Classification of a Crash Based on Its Location

The precision of a crash location also affects how the crash is perceived to relate to its surroundings. Clearly, for example, a crash that occurs on the mainline but within 3 ft (1 m) of an entrance ramp may very likely be attributed, in terms of location, to the ramp itself, depending on the nature of the crash. As that distance increases beyond 3 ft (1 m), however, it becomes more difficult to classify the crash in terms of location. The problem becomes greater when there are variations among functional units in classifying whether a crash is affected by a particular feature, such as an intersection.[24] In that example, one study classified all crashes within 100 ft (30.5 m) of an intersection as intersection related. Hence, for meeting that criterion, one would want a relatively precise measure of the crash location.

There are differences, of course, about what constitutes an intersection-related crash. In Virginia, for example, a crash that occurs more than 150 ft (45 m) from the stop line is considered to be in a midblock location.[25] In a Washington State examination of bicycle collisions, however, the determination of whether a crash was intersection related depended not on a fixed distance from the intersection but on whether the investigating officer at the scene determined the crash to be related to the intersection. For example, a crash that occurred at the end of a quarter-mile queue from an intersection could conceivably be classified as intersection related if it was partly associated with the queue. Washington State applies this criterion to all collisions, not just those involving bicycles.[26] (A personal communication with Wessels clarified the definition of *intersection related*.)

Finally, a recent study that examined the impacts of “secondary crashes” on urban arterial roadways used a somewhat larger distance of 1600 m to collect all crashes that might be influenced by other crashes and then a distance as small as 200 m to develop insights about the exact nature of these influences.[27] These examples of classifying a crash as intersection related (or not) or classifying a crash as a secondary incident triggered by other crashes (or not) suggest that there are instances where the precision of the crash location is relevant to how the crash is categorized.

As an Instrument to Introduce “Intelligence” to Crash Scene Analysis

Increased precision may have its greatest promise in allowing officers to precisely identify a location that may later be studied by crash data analysts for relevant contributing factors. For example, Wang et al. pointed out that when one state had a crash report form that included a question about whether the crash occurred within a work zone, later study of a few work zone sites revealed that “as many as 77% of the reported crashes were not coded as construction-zone accidents."[28] The study went on to suggest the use of smart software as a possible remedy for helping officers analyze a crash scene. An alternative or complement, were the precision of the location of relevant features such as work zones to be substantial, would be for the officer to record the location and then for analysts or automated software to pinpoint which crashes may have been affected by work zones or other relevant features. FHWA has an ongoing project where the development of an expert system, rather than a standard report form, would be used by officers to investigate a motor vehicle crash (unpublished data).

A key distinction here is that more precise locations may add information that, although available on the police reporting form, is not always included with the crash. For example, should one wish to study the impacts of horizontal curvature on crash rates, one would want to ensure that one knew which crashes had occurred within the curve and which had not. One study categorized relatively short tangent lengths as being less than 350 ft (107 m).[29] When that is the case, we suggest that a precision of less than 0.1 mi (158 m) may become important if curve information is otherwise not clear from the crash report.

Cases Where More Detailed Features Were Used

Zador et al. also illustrated how specific aspects of a crash may be used. When studying relationships between curvature and fatal rollover crashes, they marked the point at the edge of the roadway where the vehicle began to roll over. This is not necessarily the same point where the vehicle landed (final rest) or where the vehicle may have begun a skid (first harmful event). It is presumed that the researchers were able to know this exact reference point because, generally, fatal crashes are studied in much greater detail than nonfatal crashes. They took measurements beginning 50 ft (15 m) from the crash in 100-ft (30-m) intervals. Another effort that looked at impacts of shoulder, median, and lane width and other characteristics on crash rates used a minimum section length of 0.05 mi (79 m).[30] For that type of research, one would suspect that a precision of 200 ft (60 m) would be insufficient in some instances.

Pedestrian safety is another issue that may benefit from better reporting of crash locations, although an example from the literature is unrelated to motor vehicle crashes per se. Eck and Simpson identified hazards that contributed to pedestrian falls, such as slippery surfaces and openings in the walkway.[31] Knowing where such a fall occurred, e.g., within a few feet, could be relevant if the fall were a result of an activity that occurred within a short amount of walkway, such as reconstruction of a roadway that eliminated a sidewalk for a single block.

Cases Where Greater Precision Probably Was Not Needed

On the other hand, several components of studies do not directly call for greater precision of the crash location. For example, one study used section lengths between 0.5 and 10.0 mi (792 m to 15.8 km), and the researchers were able to obtain sections where geometric characteristics such as lane width, shoulder width, shoulder type, etc., did not vary within the section.[32] For such a study, it is questionable as to whether a precision of 30 ft (9 m) would be substantially better than a precision, say, of 200 ft (60 m). Other investigators have noted that for urban sections, where geometric characteristics change more often than for rural sections, section lengths of 0.5 to 5.0 mi (792 m to 7.9 km) could be selected with homogenous geometric characteristics.[33] One can envision instances where the results might be mixed as to whether better location information would be beneficial, as might be the case with selective enforcement to reduce speeding.

LIMITATIONS OF THIS STUDY

1. *The sample size of crashes was very small*. Thirty-two crashes were possibly suitable for analysis; generally, there were around 30 suitable responses for each survey question. Given that almost a year was required to collect these crashes, it seemed worthwhile to use the available data; still, it would have been desirable to have a much larger sample.

2. *The number of survey respondents was very small*. We targeted crash data analysts either familiar with the area or interested in GPS, with 17 written responses and 1 oral response as a result. Although some responses represented more than one person, this still was a relatively small effort describing a specific geographical area.

3. *The crash data analysts' survey was flawed*. One respondent wrote that the survey was so difficult that "if this had not been assigned to me to do, I would have thrown it away. . . ." Another respondent implied that for all five of the descriptions, the crash location was given, whereas in reality the location is not always known. The latter issue could certainly be addressed by a substantially larger sample of crashes. The former issue may have been valid, although no other respondents indicated that the survey was too difficult to complete, and at least one respondent wrote that the survey was useful. Finally, it is possible that even though greater precision might not affect "consideration" of countermeasures, it might affect their implementation. Thus, one could argue that the survey did not ask the right question.

4. *Only a portion of the GPS implementation was addressed*. This effort was concerned only with using GPS receivers to collect the data and identifying a location that could be given geographical coordinates. The next step would be to use these data in conjunction with a GIS.

5. *Hypothetical scenarios were presented*. In reality, one would likely not use a GPS receiver to measure distances. Instead, one would use the receiver to collect one point and then if one wanted other points relative to this first point, one would use a wheel to measure these distances. The receiver would be used to determine real-world coordinates for each of the three points defining the crash location. The distances were included in the survey to give respondents an opportunity to find out whether knowing those two extra points was beneficial, but it is possible that using the distances between these points adversely affected the survey results.

6. *Perfect precision is not guaranteed with GPS or with defining the crash location as three separate points*. Although for comparison purposes, GPS results were presumed perfect, there will be a tolerance of 2 m or less, based on the literature and informal tests we conducted. Further, the reality is that any location measures, whether GPS-based or not, would be put into another format (e.g., GIS, link-node), which could induce additional error. Finally, even if one recorded the first harmful event, first point of impact, and final rest, human error could remove any precision gained from recording all three points unless they are recorded consistently. When greater precision is needed for crash reconstruction purposes, electronic surveying equipment is available, as has been suggested by representatives from several states.

7. *The technology was not perfectly used*. Leaving the receiver on at all times would probably have decreased the time waiting to obtain a reading from the satellites. In addition, a wheel was not always available for obtaining accurate ground measurements; this would have affected some of the survey responses, especially those questions that reflected the distance of the crash (when defined as a single point) from the appropriate landmark.

CONCLUSIONS

Several conclusions can be drawn from this study:

1. Using the technology and methods employed in this effort, the use of hand-held GPS units required more time, rather than less time, at the crash site. Improvements in the software, the GPS units, and how they are used will likely improve the speed with which these data are collected. Further, using GPS at the crash site may speed up crash records processing overall. For example, if the use of a receiver requires x extra amount of time at the crash scene, it may be that the resultant GPS data reduce crash records processing time by $2x$ elsewhere. Yet, these benefits are likely not to be garnered by the same agency. For example, law enforcement may spend extra time and effort at the crash scene while the state motor vehicle department reaps the benefits of GPS data collection.

2. A substantial number of errors cited by survey respondents resulted from mistakes in accuracy in addition to mistakes in precision. Although the crash data analysts did suggest cases where the more precise locating methods (that could delivered by GPS) would have been beneficial, respondents also cited occasions where human error was responsible (e.g., identifying the wrong route rather than being a particular distance from the correct location). Examination of Table 3 suggests, but does not prove, that there are cases where improved precision does not affect consideration of crash countermeasures.

3. Recording only one point as the crash location has the potential to at least address the errors associated with crash locations as being inaccurate. Presuming that the surrounding roadway features are correctly coded and that conclusion 2 is on target, the use of GPS to define a single point as the crash location should eliminate some of the mistakes associated with locating crashes, provided that common standards are agreed upon for how to define the crash location as a single point. One respondent pointed out that 10 ft versus 50 ft (3 m versus 15 m) could be critical in an instance where it changed the nature of the crash from being at two intersecting roads to being at a commercial driveway.

4. Recording multiple points (e.g., first harmful event, first point of impact, and final rest) as the crash location does not necessarily affect evaluation of crash countermeasures. Although we had hoped the survey results would show otherwise, for the five crashes selected, the additional information associated with recording the crash location as three points often did not affect consideration of countermeasures.

5. There are, however, cases where multiple points are instrumental for identifying crash countermeasures. One respondent gave an instance where these detailed data could be very useful: removing a tree from a recovery zone, where environmental concerns would not allow the tree to be removed unless it definitely posed a threat. If one examines the second crash in Appendix D, it is clear that if one did not record the point of final rest and the crash diagram were not available, then one would not necessarily know whether the tree had affected the outcome of the crash. Examination of the literature lends further support to this conclusion: there were several occasions where the extra precision associated with multiple points for defining the crash location would be beneficial.

6. Hand-held receivers give the option of collecting crash data outside the vehicle. Although it is tempting from a data collection standpoint to arbitrarily decide that the location of the police cruiser should be where one collects satellite data to define a crash location, this decision does not take full advantage of the extra precision offered by GPS. Although this would address accuracy issues, it would not address precision issues, which some respondents did identify as being relevant.

7. Troubleshooting/training should be included when estimating the time required for GPS efforts. Although the phrase "training is essential" is trite, a simple practical consideration is that even for this small-scale GPS implementation in a single agency, substantial time was required by both the patrol officers and the managing officer to ensure the necessary data were collected. Even at the study's conclusion, we were still learning about organizational or technical methods for applying this technology. A salient example is the vendor's suggestion that the receiver should be left turned on at all times: doing so would probably have increased the time to record the GPS locations, although the time spent mentally determining the crash locations would have been unaffected.

The final thought about whether, and if so, how, to implement GPS stems from the following observation. The literature, the survey responses, and anecdotal information suggest that imprecise crash locations (e.g., the crash is located in the right general area but not in an exact spot) and inaccurate crash locations (e.g., the crash is located in the wrong location altogether) hamper identification or evaluation of countermeasures. Yet it is *possible* for these types of errors to be avoided even using only tools available in 1970: a wheel can provide precision within a meter, error checking can avoid gross misidentifications, and any crash records computer system can be well documented so that both users and providers understand how the data are collected. The fact that these errors persist, then, does not mean that we should ask whether it is *possible* for a technology to eliminate a certain type of error. Instead, we should ask whether a technology has a high probability of eliminating the type of error through automation.

An example is the use of GPS to collect multiple points (e.g., first harmful event and final rest) at a crash scene. To *distinguish* between these two points, one must be able to accurately recognize them at the crash site; hence, the potential for human error has not been eliminated by this technology. To be guaranteed of recording the crash location as being in the proximity of either, however, one does not need to define them; instead, one needs only to activate the receiver. This latter tack does substantially reduce the potential for human error. In short, the lesson from this example is that GPS would probably at least allow one to be confident that the crash will be correctly located if one would be satisfied with any point that represents a possible crash location, whether that point be the first harmful event or final rest. To be guaranteed of selecting only one of these, however (e.g., to be always sure that the crash location will be defined as the first point of impact and not the point of final rest), then GPS alone is not enough. One must also address the training issues that persist with more conventional technology.

In brief, we return to the discussion of the three types of errors: (1) those that arise from not defining the crash location in a uniform manner, (2) those that arise from an imperfect measuring device, and (3) those that arise from relevant features, such as guardrail, not being coded perfectly. Error type 1 will be resolved only through human improvement, whereas GPS technology and a wheel both have the potential to address error type 2. Error type 3 will depend on the environment in which the crashes are coded, especially the relevant standards for storing the locations of roadway features. If this environment is a GIS platform, for example, then using GPS technology would encourage greater consistency between how roadway features and crashes are located.

RECOMMENDATIONS

1. *At least record motor vehicle crashes as an agreed-upon single point.* Although the first harmful event appears to be a logical choice and may be the standard employed by law enforcement agencies, it would be beneficial to document this decision as GPS is used more often to collect motor vehicle crash data. The important aspect here is for users of GPS technology to agree on what constitutes the crash location: even if some point other than the first harmful event were to be used, at least a common standard should be established.

2. *Collect more detailed crash location information in at least one future pilot effort*. It would be worthwhile to determine whether a larger set of crashes supported or refuted the conclusions drawn here regarding the utility of more precise crash data. That is, in a larger scale effort, would knowing the first harmful event, first point of impact, and point of final rest prove more or less useful than what was found to be the case in this effort? One way to do this would be to carry this project into a second phase, where crash data analysts could upload GPS crash data into a GIS format. Then one could examine whether detailed crash

location information was beneficial or if recording only a single point as the crash location was sufficient. If these extra location data were collected for an area where detailed roadway data are being obtained, then one could compare the compatibility of the crash location standard and the roadway standard. For example, if a 300 foot (90 m) section of guardrail will be recorded as a GIS line feature, then one can truly determine whether knowing the trajectory of a run off the road crash is more useful than simply knowing a single point where the vehicle left the roadway.

3. *In future efforts where new data collection methods are used, provide explicit feedback to the appropriate law enforcement agency about the benefits derived*. The use of GPS actually increases the workload for the investigating officer, at least in this learning phase. That being the case, it is reasonable for the officer to want to know whether the extra time spent collecting crash data has any real benefit. If such benefits are found to exist, then they need to be relayed back to the officer.

4. *Monitor software, hardware, and methodological developments as appropriate*. The technology in this field changes rapidly, and certain aspects of data collection may become more feasible as the technology improves. One of the most frustrating aspects of GPS data collection, which was waiting for the receiver to read the satellite locations, is an area that may well be improved as the technology advances. For example, the use of an external antenna attached to the vehicle, although possibly increasing the speed with which the receiver finds the satellites, could alleviate this problem but may induce additional problems with interference, as suggested by Brich et al.[34] Another thought is the use of the data dictionary: when using the hand held GPS receivers, the data dictionary did not simplify matters for recording the crash location, but this may change as either the technology improves or the nature of the application changes. Finally receiver improvements themselves are worthy of examination.

5. *Consider adding a spot to the FR-300P that allows the officer to indicate where the GPS reading was taken: first harmful event, first point of impact, final rest, or other*. There may be cases where the officer is unable to stand directly at the desired point with the receiver, or there may be cases where the officer cannot accurately identify the desired point (e.g., an officer knows exactly the point of final rest but not the first point of impact nor first harmful event). Such an addition could be useful even without GPS as it would serve as a check on how the crash location was coded.

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APPENDIX A: POLICE SURVEY COMPLETED FOR EACH CRASH

(1) **Complete crash case number**: (YY / MM / DD / Event Number) 96 /__ /__ /_

(2) **Conventional method of locating crashes**:

- How long does it take to *normally* determine what is the crash location? _____minutes

- How would this location *normally* be measured?
  ___ odometer
  ___ line of sight
  ___ pacing
  ___ tape measure or wheel
  ___ other: ___________________________________

- How long did it take to measure this distance using the method above? _____minutes

- What is the exact distance from the landmark or intersection to the crash location? _____feet (as measured with a wheel)

- How long did it take to measure this distance? _____minutes

(3) **Alternative crash location definition**

(**A**) What is the *first harmful event* for this crash?

The *first harmful event* is defined as where the driver began to deviate from the normal course of travel: e.g., braked suddenly, crossed over a double yellow line, left the roadway, or began a skid. (If you prefer, you may simply mark this on the diagram as "point **A**")

____

(**B**) What is the *first point of impact* for this crash?

The first *point of impact* is defined as where the vehicle first strikes a pedestrian, vehicle, pole, or any other object on or off the roadway. (Or you may mark this on the diagram as "point **B**")

____

(**C**) What is the point of *final rest* for this crash?

The *point of final rest* is defined as where the crash terminated. For example, this might be where the vehicle finally stopped or the pedestrian landed. (Or you may mark this as "point **C**")

____

(D) How long did it take to determine points **A**, **B**, and **C**? _____ minutes

- What is the distance between the *first harmful event* (**A**) and the *final rest* (**C**)? ______feet

- What is the distance between the *first harmful event* (**A**) and the *first point of impact* (**B**)?______feet

- What is the distance between the *first point of impact* (**B**) and the *final rest* (**C**) ______feet

- How long did it take to measure these three distances? _____ minutes

(4) Record the crash location using the Trimble GPS Receiver:

- Place or hold the receiver flat in the palm of your hand. If possible, avoid using the receiver within five minutes of the hour.

- Press the bottom button to turn on the receiver. If it is dark, you may toggle this button in order to activate the backlight of the receiver. (This should be kept to a minimum as it will reduce battery life.)

- Use ← or→until "1. Data Capture" is blinking". [Press ↑ to select.]
  "1. Open Rov. File" [Press ↑ to select]
  When the number of points shown in the upper right corner becomes 120, then
  select "3. Close File" [↑]
  Select "Yes" to close file. [↑]
  Write the GPS file name for first harmful event (point **A**) *here*: **R**__________

  "1. Open Rov. File" [Press ↑ to select]
  When the number of points shown in the upper right corner becomes 120, then
  select "3. Close File" [↑]
  Select "Yes" to close file. [↑]
  Write the GPS file name for the first point of impact (point **B**) *here*: **R**__________

  "1. Open Rov. File" [Press ↑ to select]
  When the number of points shown in the upper right corner becomes 120, then
  select "3. Close File" [↑]
  Select "Yes" to close file. [↑]
  Write the GPS file name for the point of final rest (point **C**) *here*: **R**__________

  Press the "esc" key to return to the main menu. [↑]
  Turn the receiver off by holding down the bottom button for five seconds.

- How long did it take to use the GPS receiver? _____ minutes

(5) Were there any difficulties with using the GPS receiver that others should be aware of?

____

____

At the end of the shift: charge the battery and attach a copy of the FR-300P to this form.

APPENDIX B: COMPARISON OF GPS COMPUTED AND MEASURED DISTANCES

The table shows the crash number, the distances measured or estimated by the officer, the distances computed using the GPS receiver, and explanatory notes for each crash. "A" refers to the *first harmful event*, "B" refers to the *first point of impact*, and "C" *refers to the final rest*. All distances are given in feet. The left side of the table shows the disparity when the crash location is defined as a single point, whereas the right side of the table shows the disparity when the crash location is defined as three points. Under the first category (defining the crash as a single point), two separate location methods are considered: the conventional method, where measurements for nonfatal crashes are usually taken with the odometer or estimated by line of sight, and the "wheel" method, where the distances are measured by rolling a wheel along the ground. The distances in this first method refer to the distance from the intersection or street as shown at the top of the FR-300P report form.

Crash Number	**Crash Location Defined As Single Point**		**Crash Location Defined As Three Separate Points**						**Notes**
	Line of Sight or odometer	**Wheel**	**Distances Measured by Officer (ft)**			**Distances Computed by GPS Receiver (ft)**			
			A-C	A-B	B-C	A-C	A-B	B-C	
1	50 ft	37	22	11	8	37	42	6	
2	100 ft	162	24	18	6	401 504	63 113 221 100	447 555	Two "A" points recorded by GPS receiver Two "B" points recorded by GPS receiver Base station data temporarily not available for correction purposes (not fault of officer)
3	0.3 mi	unknown	30	10	20	37 102	18 122	40	Officer's distances are estimates (no wheel available) Two "A" points recorded by GPS receiver Data correction uses two time periods
4	0.2 mi	unknown	80	60	0	147	138	22	Officer's distances are estimates (no wheel available) Distance A-C thought to be "80" but difficult to read
5	0.1 mi	unknown	150	140	10	302	251	52	Officer's distances are estimates (no wheel available)
6	0.1 mi	0	80	80	0	0	179	0	Officer's distances are estimates (no wheel available) Point "C" not recorded by GPS receiver (this may have resulted from data dictionary malfunctioning)
7A	0	61'8"	25	25	0	210	64 212	3 147	Note there are two "B" points recorded by officer This is same as crash directly below with two possible interpretations
7B	--	--	25	25	0	65	33 36	61 83	Note that the two "B" points are in opposite directions: hence there is a very substantial difference between them
8	50 ft	unknown						57	No point "A" recorded No survey form completed
9	½ mi	½ mi	182	64	118	187	79	108	Fatal crash (hence very precise measurements likely)

	[Paced as this was a fatal crash]	copied							
10	50 ft	50 ft copied	75	75	0	103	92	11	
11	0.6 mi	0.6micopied	25	15	10	34	15	19	
12	at intersect.	0	20	20	0		27 35		No point "C" recorded with GPS receiver. However, this may not be significant, as "B" appears to be same as "C" from survey form. Point "B" spans two time periods and two distinct points are available; they are only 15.8 feet apart. (As explained in text, doing data correction procedure after combining base station files showed that "true" location was on a line between these two initial points, with the true location being 9.9 feet from one and 5.9 feet from the other.)
13	at intersect.	12	50	50	0	112	112	10	AC and AB same due to rounding (112.0 and 111.8, respectively)
14	0.1 mi *[paced]	0.1 mi copied	30	30	0	55	53	2	
15	at intersect.	0	25	20	15	63	41	39	
16	0.6 mi	0.6 mi copied	50	25	25	93	52	42	
17	0.1 mi [paced]	0.1 mi copied	50	50	0	99	88	11	No wheel used to take measurements
18	0.3 mi [paced]	blank	30	20	10	84	60	25	No wheel used to take measurements
19	200 ft	200 ft copied	100	25	75	179	45	136	No wheel used to take measurements
20	0.2 mi	1500 ft	200	100	100	248	165	83	Only one point recorded by officer because receiver took so long to get a fix. Measurements taken later by the authors in an attempt to address receiver error.
21	2 mi	2micopied	45	35	10	62	20	48	Raleigh base station used
22	300 ft	0.1 mi	20	0	20	52	8	46	Raleigh base station used
23	150	150 ft copied	20	20	0	32	41	11	Raleigh base station used
24	at intersect	0	30	30	0	24	31	15	Raleigh base station used

25	at intersect	0	50	50	0	96	106	10	Raleigh base station used
26	150 ft	50	30	30	0	49	46	5	Raleigh base station used
27	100 ft	200 ft	15	15	0	6	4	5	Raleigh base station used
28	0	blank	123	0	123	115	2	115	Officer suggested that nearby power lines slowed GPS receiver
29	0	0	30	30	0	47	45	7	
30	0.1 mi	0.2 mi	15	15	0	14	12	7	
31	at intersect	0	25	25	0	51	49	2	
32	0.2 mi	blank	150	130	20	237	221	26	

APPENDIX C: COMPARISON OF TIMELINESS FOR GPS AND CONVENTIONAL METHODS

The table compares the timeliness aspects for the different methods of defining a crash location. The left half contains information pertaining to defining the crash location as a single point, and the right side addresses defining the crash location as three points: first harmful event, first point of impact, and final rest. For both categories, the column to the left "Determination of single point" or "Determination of the three points" shows how long it took the officer to determine the crash location upon arriving at the scene of the incident.

Under the first category (defining the crash as a single point), two location methods are considered: the conventional method, where measurements for nonfatal crashes are usually taken with the odometer or estimated by line of sight, and the "wheel" method, where the distances are measured by rolling a wheel along the ground. Under the second category (defining the crash as three points), the two location methods considered are the use of the wheel and the use of the GPS receiver. Times are given in minutes.

Crash Number	**Crash Location Defined as Single Point**			**Crash Location Defined as Three Separate Points**		
	Determination of Single Point	**Measured by Line of Sight or Odometer**	**Measured with a Wheel**	**Determination of the Three Points**	**Measured with a Wheel**	**Measured with GPS**
1	1-4	1	1	1	3	14
2	1-4	1	2	1	4	18
3	1	1	unknown	2	4	15
4	1	1	unknown	unknown	1 (visual estimate)	20
5	unknown	unknown	unknown	unknown	1 (visual estimate)	15
6	1	1	0	unknown	1 (visual estimate)	10
7A	10	45	5	10	15	15
7B	--	--	--	--	--	--
8	unknown	unknown	unknown	unknown	unknown	unknown
9	15	60	1	15	15	15
10	2	8	1	5	2	12
11	5	5	1	10	5	8
12	2	1	0	5	2	12
13	2	1	2	5	10	8
14	2	2	.25	5	5	7
15	2	1	0	8	10	8
16	2	10	1	5	2	10
17	2	10	1	10	5	10
18	2	10	1	5	10	12
19	1	10	1	5	10	blank
20	1	1	2	3	1	3 (plus officer

						indicated frustration)
21	2	2	2	10	5	12
22	2	1	1	10	5	10
23	2	1	1	blank	2	10
24	2	1	0	5	5	15
25	2	1	0	blank	5	10
26	2	1	1	5	5	10
27	1	1	1	5	5	blank
28	10	15	15	10	15	10
29	5	2	1	2	5	12
30	1	1	1	5	5	12
31	1	1	1	5	5	15
32	2	1	2	10	1	10

APPENDIX D: SURVEY SENT TO CRASH DATA ANALYSTS

To: Bob Brietenbach, VCU Transportation Safety Training Center, Richmond
Budd Cox and Sgt. Gary Payne, Virginia State Police
Dr. Jonathan Earl, Albemarle County Police Department
Bob Hofrichter, VDOT Salem District
Jeff Hores, VDOT Culpeper District
Sgt. Larry Lam, Virginia State Police
Jim Marshall, City of Charlottesville Traffic Engineering
Lam Phan and Angelisa Jennings, Virginia Department of Motor Vehicles
Bob Rasmussen, VDOT Central Office
Sgt. Ronnie Roberts, City of Charlottesville Police Department
John Shifflett and Angela Tucker, VDOT Charlottesville Residency
Gerald Venable, VDOT Central Office
Eric Vogel, VDOT Fredericksburg District
Juandiego Wade and Tex Weaver, Albemarle County Planning Office
Bill Wanner and Hannah Twaddell, Thomas Jefferson Planning District Commission
Carter White, VDOT Warsaw Residency
Tim White, VDOT Central Office
Dave Wyant, VDOT Central Office

Over the past year, the Albemarle County Police Department in conjunction with the Virginia Transportation Research Council has been using hand-held Global Positioning System (GPS) receivers to collect the location of motor vehicle crashes. In addition, the officers have also determined the crash location with more conventional methods, such as using a tape measurer, odometer, or line-of-sight estimation. While some of these methods are more precise than others, each method comes with some cost in terms of the amount of extra time the officer must spend at the scene of the crash.

We would like to know what benefit, if any, is obtained when one uses a more precise method to locate a crash. In other words, suppose a crash in reality occurred 25 feet away from an intersection. We would like to know if it makes a difference to the analyst if the crash is recorded as being 50 feet, 100 feet, or 500 feet from the intersection. It may be the case that this affects the types of countermeasures considered, or it may be the case that there is no effect at all.

The attached survey contains five crash descriptions. Each crash description includes a narrative about the events that transpired, a crash diagram, and the crash location with respect to relevant landmarks. For each crash, we would like to know whether or not defining the location in a more precise manner is worthwhile, given that time and resources may increase depending on how precise that location needs to be. The focus of the survey is on **potential** countermeasures since in reality you would want a complete crash history to definitively identify problems at a particular site.

If you are not someone who routinely performs this type of work, we would still like to have your input. Each of you has been selected to participate in this survey because of your role as it relates to traffic and highway safety. If you have additional views that you feel are not reflected in your responses please do not hesitate to fill in the free response section at the end of the survey. If other persons in your organization would like to provide input, you may either make a copy of the survey yourself or contact John Miller for additional copies.

You may mail your response to John Miller, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, Virginia, 22903 (FAX is (804) 293-1990, Internet address is jsm3f@virginia.edu and VDOT VAX address is MILLER_JS) **or, if you prefer, you may call John at (804) 293-1999 and give your response over the phone.** Please call, mail, or fax your survey by April 18.

Thank you, in advance, for your assistance. Your time and effort will help us learn how we can improve highway safety without unduly burdening law enforcement.

For each crash, please do the following:

Read the crash narrative and review the corresponding diagram. Imagine that multiple crashes of the same type have occurred at the same location. Then, **for the first question under each diagram**, consider what types of countermeasures might potentially reduce these crashes. The countermeasures may be engineering related, such as retiming a traffic signal, moving a stop line, improving roadway alignment, etc. The countermeasures may also be driver related, such as enforcement or education initiatives. The countermeasures could be vehicle or EMS related if you deem those appropriate. You may also identify other countermeasures not mentioned here: there are no "wrong" answers for this survey!

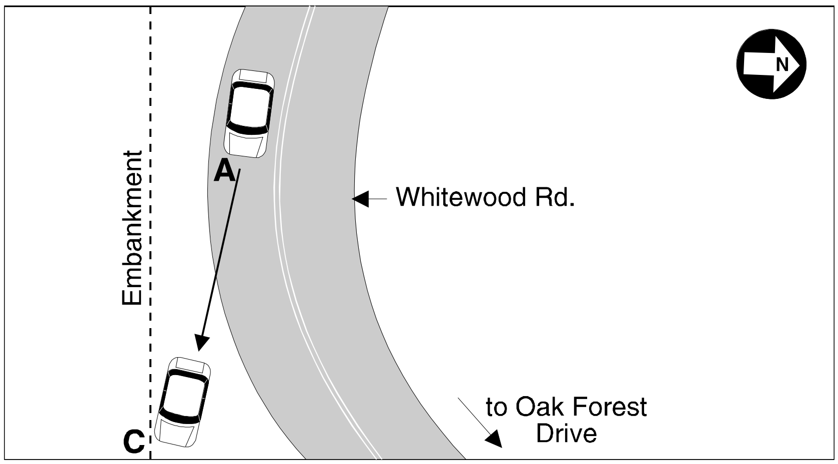
Then, for **each of the questions that follow**, indicate whether the additional information presented would cause you to change your opinion about the utility of those countermeasures. For example, after reading a crash narrative you may initially believe that closing nearby driveways would be worth considering. Yet if additional information causes you to believe that the answer is to instead add a left turn bay, then we need to know that. On the other hand, if the additional information does not affect your decision, then that is important as well.

In the questions that follow, the phrase "**visually estimated**" means that no measuring device is used: instead the officer simply estimates the indicated distance by line of sight. On the other hand, the word "**measured**" means that the officer uses a wheel or tape measurer to measure the indicated distance.

You are welcome to use additional space if necessary. If any part of this survey requires clarification, please do not hesitate to call John Miller at (804) 293-1999.

Crash #1

Narrative: At 2:30 p.m. on a rural two lane road (Whitewood Road), vehicle 1 hit a patch of ice (point A) at which time the driver lost control of the vehicle. The vehicle then slid off the right side of the road, struck an embankment, and then came to rest (point C). The weather was misty and the road surface was wet. The vehicle was traveling at 30 mph in a 35 mph zone but the officer had noted the maximum safe speed was 25 mph. There were no defects associated with the driver, roadway, or vehicle, and the alignment is a graded curve. Initially, the crash location is **visually estimated** to be approximately 150 feet from Oak Forest Drive.



- *Using only the information presented above*, what kinds of countermeasures might you ***consider*** had many crashes similar to this one occurred?

  ____

  ____

- Suppose the officer had **measured** the distance between the intersection and the crash location and found that it was only 50 feet, rather than 150 feet, away from Oak Forest Drive. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose the officer had **visually estimated** the distance between points A and C as 30 feet. Would this knowledge affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

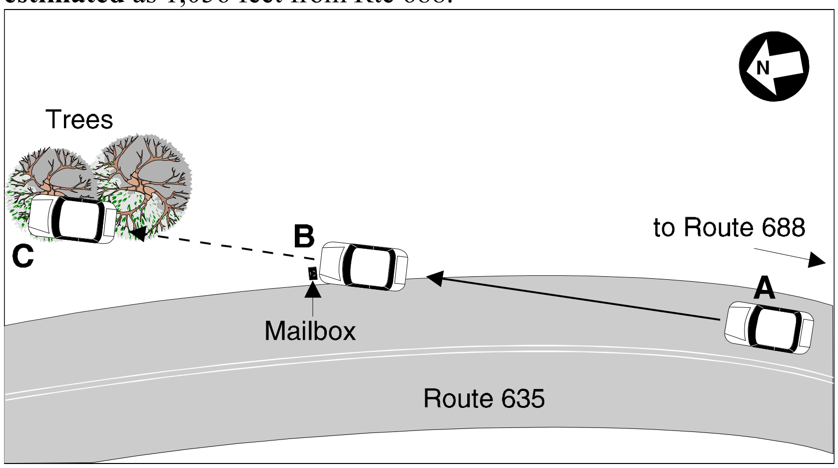
- Suppose that the officer then **measured** the distance between points A and C as 49 feet. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

Crash #2

Narrative: Vehicle 1 was northbound on Rte 635 when it ran off the right shoulder at point A. The vehicle struck a mailbox (point B) and went down the fillslope. (The fillslope here is the connection between the outer edge of the shoulder and the natural ground). The vehicle then came to rest after striking a tree at point C. The speed limit was 55 mph, the maximum safe speed estimated by the officer was 40 mph, and the vehicle speed was not known. The alignment of the roadway is graded curve, and the fillslope increases in steepness from point A to point C. It was snowing so the surface was wet, and the accident occurred during nighttime hours. The driver had been drinking, but the officer could not tell if the driver's ability had been impaired. No defects were associated with the roadway or vehicle. Initially the crash location is **visually estimated** as 1,056 feet from Rte 688.



- *Using only the information presented above*, what kinds of countermeasures might you ***consider*** had many crashes similar to this one occurred?

  ____
  ____

- Suppose that the officer **measures** the crash location as being 1,647 feet rather than 1,056 feet from Route 688. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose the officer had **visually estimated** the distance between points A and B to be 100 feet, while the distance between points B and C was also **visually estimated** as 100 feet. Would this knowledge affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

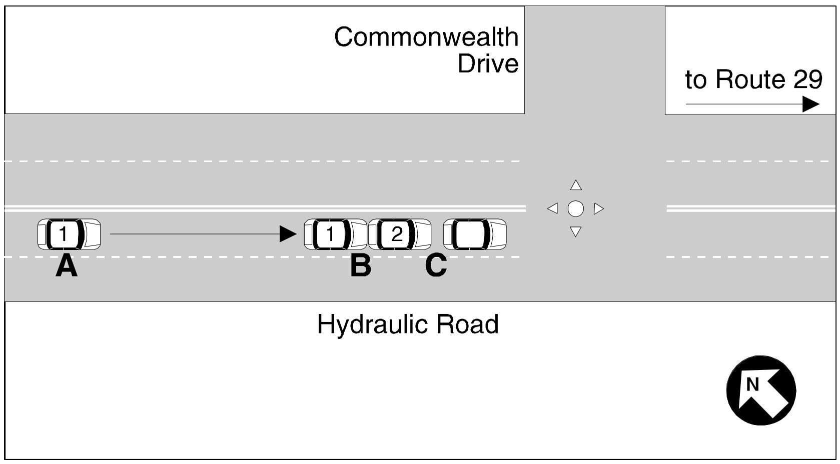
- Suppose the officer had **measured** the above distances, and found that from A to B was 165 feet while the distance between B and C was 83 feet. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

Crash #3

Narrative: Vehicle 1 was eastbound in the left hand lane of Hydraulic road, a four-lane undivided arterial, and the driver was attempting to get into the right hand lane. Vehicle 2 was stopped at a traffic light in the left lane when vehicle 1 began braking at point A. Vehicle 1 then skidded and then rear-ended vehicle 2 at point B. The speed limit was 40 mph, the maximum safe speed was 40 mph, and vehicle 1 was traveling at 25 mph. It was dusk and raining, so the surface was wet. There were no defects associated with the roadway or the vehicle. The officer charged the driver with following too close, and the crash is **visually estimated** to be 50 feet from the intersection of Commonwealth Drive.



- *Using only the information presented above*, what kinds of countermeasures might you ***consider*** had many crashes similar to this one occurred?

  ____

  ____

- Suppose the officer had **measured** the crash as 37 feet, rather than 50 feet, from the intersection. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose the officer had **visually estimated** the distance between points A and B as 11 feet. Would this knowledge affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

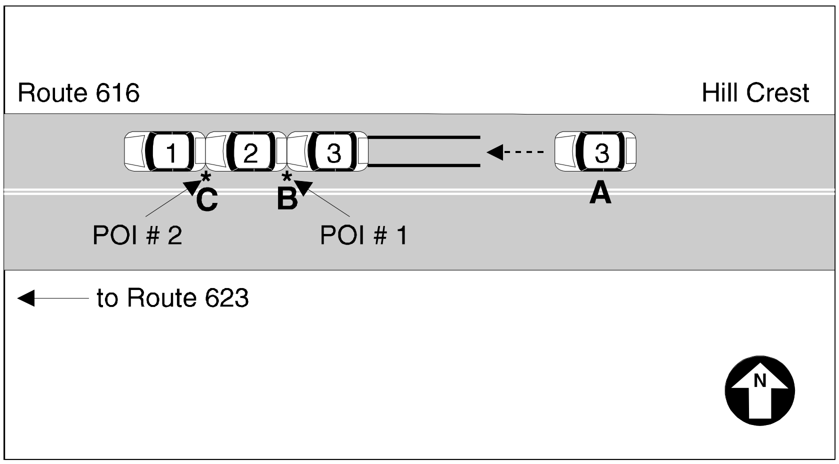
- Suppose the officer had **measured** the distance between points A and B as 42 feet. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

Crash #4

Narrative: At 3:45 in the afternoon vehicles 1 and 2 were stopped on a two-lane secondary road (Route 616) because of an accident north of their location. At point A, Vehicle 3 crested a hill and noticed the stopped vehicles. Vehicle 3 then slid into vehicle 2 at point B, and then slid into vehicle 1 at point C. The speed limit was 55 mph, vehicle 3 was traveling at 50 mph, and the maximum safe speed was 45 mph. The alignment may be described as hillcrest straight, and since it was raining at the time the surface was wet. The roadway pavement was slick and there were no defects associated with drivers or vehicles. The crash is **visually estimated** to be 1000 feet away from Rte 623.



- *Using only the information presented above*, what kinds of countermeasures might you ***consider*** had many crashes similar to this one occurred?

  ____

  ____

- Suppose the officer had **measured** that the crash was actually 1200 feet, rather than 1000 feet, away from Route 623. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose the officer had **visually estimated** the distance between points A and B as being 60 feet. Would this knowledge affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

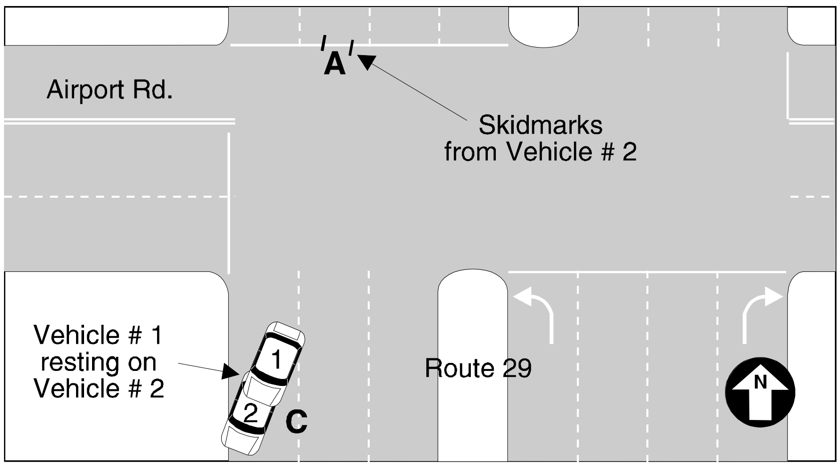
- Suppose the officer had **measured** the distance between points A and B as being 138 feet. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

Crash #5

Narrative: A few minutes after midnight, vehicle 2 was stopped at the intersection of Route 29 and airport road, in the southbound lanes. The light turned green and vehicle 2 stalled. At that point, vehicle 1 then struck vehicle 2 from the rear (shown as point A). Both vehicles came to rest at point C. Driver 1 stated that he did not see the vehicle in front of him, the traffic signal, or the intersection, and that he had fallen asleep. The speed limit was 55 mph, vehicle 1 was traveling at 59 mph, and the maximum safe speed was 55 mph. The alignment may be described as straight, and the surface was dry. There were no defects associated with the drivers, vehicles, or the roadway, and charges are pending against driver 1. The crash is estimated to be right at the intersection of Airport Road and Route 29.



- *Using only the information presented above*, what kinds of countermeasures might you ***consider*** had many crashes similar to this one occurred?

  ____

  ____

- Suppose the officer had **visually estimated** the distance between points A and C as 123 feet. Would this knowledge affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose the officer had **measured** the distance between points A and C as being 115 feet. Would this improved precision affect your consideration of potential countermeasures?

  ☐ Yes ☐ No

  Reason:____

- Suppose you only knew that the crash had occurred in the vicinity of the intersection: you did not know about points A and C. Would your consideration of potential countermeasures be affected?

  ☐ Yes ☐ No

  Reason:____

FREE RESPONSE

→ Can you recall instances in your past experience where greater precision or greater accuracy for locating crashes was needed? Please describe them briefly.

____

____

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____

→ Do you have any views not yet reflected in the survey on the potential utility of, or obstacles to, using GPS to record motor vehicle crash locations?

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→ The previous descriptions provided you with very limited information. Even with a complete crash history, you would still want much more extensive roadway inventory data at your disposal when analyzing specific segments or spots. Such data might include information on lane widths, alignment, surface materials, pavement markings, signing, traffic volumes, access control, and the presence of other traffic generators. With this in mind, can you foresee instances when the **disparity** between the visually estimated and measured distances in the previous questions would significantly affect how one evaluates the safety impacts of these various roadway features?

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Thank you for your effort! Please let John Miller know if you would like to receive a summary of all the survey responses.

APPENDIX E: SUMMARY OF RESPONSES FROM CRASH DATA ANALYSTS

The tables that follow detail the survey responses by countermeasures considered. That is, if a respondent identified a countermeasure as “warning signs” then the phrase “warning signs” was placed in either the “YES” column or the “NO” column for each question. A “YES” response meant that the additional information associated with the question on the left would influence the respondent’s consideration of the countermeasure, whereas a “NO” response meant that the additional information did not affect the respondent’s consideration of the particular countermeasure. Some responses listed countermeasures, then checked “yes” or “no” but left the “Reason” blank. In those cases, it was assumed that the “yes” or “no” referred to the respondent’s countermeasures. Each countermeasure is listed only once.

Crash Data Analysts' Responses for Crash #1

Additional Information for Crash	YES Response: Influences these countermeasures	NO Response: Does not influence these countermeasures
Crash location 50 ft, not 150 ft from landmark	Warning signs (chevrons, road freezes, maximum safe speed) Roadway realignment Skid resistance, Check for shady spot [that freezes],drainage Reduction of speed limit Add stop sign Ensure adequate right of way for certain improvements Guardrail, Check embankment	Radius of curve or coefficient of friction Sanding and salting Warning signs, Guardrail Spot overlay to improve drainage Check shoulders, ditches, pipes, pavement for good drainage Delineation Roadway realignment Public education campaign
Distance from A to C estimated as 30 ft	Check vehicle speed Warning signs Roadway realignment Skid resistance Check for existence of shady spot [that freezes], drainage Guardrail Check embankment	Radius of curve or coefficient of friction Reduction of speed limit Sanding and salting Warning signs, Stop Sign, Guardrail Roadway realignment Spot overlay to improve drainage Ensure adequate right of way Check shoulders, ditches, pipes, pavement for good drainage Delineation Central question is why the vehicle left the roadway Public education campaign
Distance from A to C measured as 49 feet	May need additional "safety devices" Warning signs Roadway realignment Skid resistance Check embankment Drainage Check for existence of shady spot [that freezes] Guardrail	Radius of curve or coefficient of friction Reduction of speed limit Sanding and salting Warning signs, Stop Sign, Guardrail Roadway realignment Spot overlay to improve drainage Ensure adequate right of way Check shoulders, ditches, pipes, pavement for good drainage Delineation Check for shading Public education campaign

One respondent pointed out that the question of whether or not the additional information is relevant depends heavily on whether the roadway section is similar to or different from the nearby roadway sections. If that section is **different** from the surroundings, then the additional information is relevant to a host of countermeasures, such as pavement overlays to increase friction, curve improvements such as embankment excavation, superelevation, reduction of degree of curvature, and drainage study due to ice, pavement markings, add edgeline, raised pavement markers, delineation, and guardrail. If the roadway section is similar, then it would not affect these countermeasures substantially, although the respondent noted that improved precision and accuracy are of course desirable.

Crash Data Analysts' Responses for Crash #2

Additional Information For Each Crash	**YES** Response: Influences these countermeasures	**NO** Response: Does not influence these countermeasures
Crash location 1647 ft, not 1056 ft from landmark	Grade from centerline to edge of pavement Shoulder grade/widen shoulder Determine where vehicle ran off the road Curve improvement Guardrail Warning signs Ensure adequate right of way (to improve sight distance) Skid resistance Speed limit reduction Check fill/embankment	Warning sign or delineation DUI enforcement/education/Public education campaign Removal of trees/improve recovery area Skid resistance Guardrail
Distances AB and BC estimated as 100 ft	Curve improvement (may affect perception of curve relative to A,B) Grade from centerline to edge of pavement Shoulder grade Guardrail Warning signs Skid resistance	Warning sign or delineation DUI enforcement/education/Public education campaign Removal of trees Ensure adequate right of way (to improve sight distance) Guardrail Skid resistance Widen shoulder Speed limit reduction Check fill/embankment
Distances AB and BC measured as 165 ft and 83 ft respectively	Vehicle speed Grade from centerline to edge of pavement Shoulder grade Curve improvement Affects whether removal of hazardous objects should be considered Guardrail Warning signs Skid resistance Check fill/embankment	Warning sign or delineation DUI enforcement/education/Public education campaign Removal of trees Ensure adequate right of way (to improve sight distance) Guardrail Skid resistance Widen shoulder

One respondent pointed out that in general countermeasures such as guard rail or removal of trees to provide a wider clear zone would be affected if the stretch of roadway shown in the above scenario was different from adjacent roadway.

Crash Data Analysts' Responses for Crash #3

Additional Information for Crash	YES Response: Influences these countermeasures	NO Response: Does not influence these countermeasures
Crash location 37 ft, not 50 ft from landmark	Pavement skid resistance Sight distance Left turn lane (and retime signal accordingly) Traffic control (signal timing, visibility of signal heads) Speed limit reduction Drainage	Left turn lane (and two through lanes or a single through lane) Pavement markings for vehicles to go through intersection Warning signs Strobe light Skid resistance Overpass, supplemental signal head Sight distance Public education campaign
Distance from A to B estimated as 11 ft	Left turn lane Warning signs (e.g., perhaps too many warnings already!) Pavement skid resistance Sight distance	Pavement markings for vehicles to go through intersection Left turn lane Warning signs Strobe light Skid resistance Traffic control (signal timing, visibility of signal heads) Speed limit reduction Drainage Overpass, supplemental signal head Public education campaign
Distance from A to B measured as 42 ft	Pavement skid resistance Sight distance Left turn lane Warning signs	Left turn lane Warning signs Pavement markings for vehicles to go through intersection Strobe light Traffic control (signal timing, visibility of signal heads) Speed limit reduction Drainage Overpass, supplemental signal head Public education campaign

Crash Data Analysts' Responses for Crash #4

Additional Information For Crash	YES Response: Influences these countermeasures	NO Response: Does not influence these countermeasures
Crash location 1200 ft, not 1000 ft from landmark	Skid resistance Sight distance improvement (e.g., hillcrest removal) Warning signs (consider a queue detector as well) Reduced speed limit Access management (evaluate possible conflict points first) [This last respondent points out that reaction time would be affected but not countermeasure, but "Yes" is checked]	Warning signs Sight distance improvement Reduced speed limit Police cruiser with flashing lights Public education campaign
Distance from A to B estimated as 60 ft	Warning signs Skid resistance Sight distance improvement Verify vehicle speed Reduced speed limit	Police cruiser with flashing lights Sight distance improvement Public education campaign
Distance from A to B measured as 138 ft	Warning signs Skid resistance Sight distance improvement Verify vehicle speed Reduced speed limit	Reduced speed limit Police cruiser with flashing lights Warning signs Sight distance improvement [although one respondent pointed out driver reaction time would be affected] Public education campaign

Crash Data Analysts' Responses for Crash #5

Additional Information for Crash	YES Response: Influences these countermeasures	NO Response: Does not influence these countermeasures
Distance from A to C estimated as 123 ft	Ensure stop bar provides adequate view of the traffic signal Verify vehicle speed Reduce speed limit Examine sight distance Warning signs Strobe light	Reduce speed limit Rumble strips/change roadway texture Loss of license Strobe light Lighting Review signal timing, pavement markings, and pavement type Warning signs Conduct an investigation/analysis that considers several factors
Distance from A to C measured as 115 ft	Ensure stop bar provides adequate view of the traffic signal Verify vehicle speed Reduce speed limit Examine sight distance Warning signs	Reduce speed limit Rumble strips Strobe light Loss of license Lighting Review signal timing, pavement markings, and pavement type Warning signs Conduct an investigation/analysis that considers several factors
Only knew that crash had occurred in the vicinity of the intersection	Verify vehicle speed Verify that vehicle 1 was properly stopped Rumble strips Strobe light Warning signs [check in conjunction with signal]	Ensure stop bar provides adequate view of the traffic signal Reduce speed limit Examine sight distance Warning signs Rumble strips Loss of license Lighting Review signal timing, pavement markings, and pavement type Warning signs Conduct an investigation/analysis that considers several factors

The following quotes are from the free response portion of the survey, and have been edited or abridged as necessary. Responses that appeared in the body of the report have not been repeated here.

Can you recall instances in your past experience where greater precision or greater accuracy for locating crashes was needed? Please describe them briefly:

"A tractor trailer hit the bridge on the bypass. The police looked at one bridge and found no damage, because the truck hit the other bridge."

"While an estimated versus measured distance may make little difference to some countermeasures; routinely measuring distances accurately will help identify crash clusters or overrepresented locations (spots)."

"I have had occasion to reconstruct accidents for various reasons, including civil court cases. Accurate measurements allow you to place vehicles, debris, etc. in exact places."

"GPS would be of great value in many accidents that are located in rural environments."

"Traffic analysis of crash sites: if we had them located by coordinates and could plot them precisely we could readily see and show others where the scenes of more frequent tragedy are."

"In many cases, the crash report form is not properly recorded or an incorrect cross-street/cardinal direction is used, which makes locating accidents difficult or impossible."

"When conducting lane analyses such as HOV".

"Yes, however, your examples do not lend very much to that option. All of the [five shown] accidents are of the same nature no matter their location: distance is a constant."

"When trying to determine whether an accident is located at a driveway, the location of the crash is very important. Also, if a crash occurs at point A which is estimated by police officer A to be 400 feet from point B, but only 200 feet by police officer B, then those two crashes will be located 200 feet apart when in reality they were at the same location."

"I cannot recall any accident experience where it would be particularly useful to have had precise location of crashes. Most of the incidents where there was frequent accident experience, it was on the primary or interstate, and the existing logging systems identified the location adequately."

"Yes, greater accuracy is needed, especially for the secondary system. The relationship [of crash locations] to driveways, entrances, and other potential conflict points [is] important."

"Most fatal crashes should be marked precisely…"

"Greater precision and accuracy for locating crashes is needed for problem identification and decision making in regards to location specific data, traffic safety problems, program planning, conducting studies, and evaluations for that location."

Do you have any views not yet reflected in the survey on the potential utility of, or obstacles to, using GPS to record motor vehicle crash locations?

"GPS could be very helpful when police call about problem spots and could give exact GPS location (e.g., NOT 'about 1500 feet south of Route 29')"

"I believe GPS will allow us to be more accurate; for crash reconstruction accurate measurements may mean the difference between culpability or not."

"I believe the use of GPS would be very helpful in investigating traffic crashes in problem areas as well as serious or fatal crashes where reconstruction is needed."

"Incorrect information can skew data which alters the perception of the public when such data is disseminated to the media, legal inquiries, political figures, etc. While those reviewing the data would perceive the complications to be occurring in one spot, it could be occurring several hundred feet away. These errors can also skew the accident rate calculations on Critical Rate Lists, may not give technicians enough accidents to identify patterns at a specific location, and reduces the confidence level of those using the system. In the example of coding a crash as Route 29 when in fact it was Business Route 29, the technicians have to check the data on both the Route 29 segment as well as the Business Route 29 segment to see if there are any mis-located collisions."

"Cost, time on the scene by the investigating officer [are obstacles]. Getting just one reading (either final vehicle positions or initial contact point) would help in locating accidents."

"It will improve the accuracy of crash data locations as well as [provide] a resource."

"Time related to collecting data, keeping these data updated, and training."

"It is important to know the location of the accidents. You have done this for us in your [five] examples."

"The utility is that it will provide much more accurate location information. The obstacles that I see include the difficulty for the police officer to locate an accident after the vehicles have been removed from the roadway. How will the measurement be taken on an eight lane Interstate Highway during rush hour on the inside lane if the vehicles have been moved?"
"One issue to think about is crash selection: a police officer can code a crash as being within 1/3 of a particular landmark while another coder would place the same crash within ½ mile of the same landmark. Thus to obtain all crashes within a specific section, you still have to examine individual reports and/or place some ranges on your query: e.g., to get all crashes exactly 1/5 of a mile from a point, you might query for crashes that are between 0.15 and 0.25 miles away."
"I think the use of GPS by law enforcement is a very good idea which needs to be more fully implemented. With GPS, high accident locations could be more easily identified on the secondary system, especially in the rural areas. I use the word 'high' in a relative sense because the accident rate in the predominantly rural areas is going to be much lower than in more urban settings. If such locations can be identified sooner, than remediation may be less expensive and may actually postpone more elaborate and expensive construction."
"Generally speaking, it should always be more helpful to have accurate measurements. Pacing, or using a measuring wheel, is certainly better than a 'visual estimate.'"
"GPS locators are becoming more reasonably priced. Their use will assure a constant level of accuracy in accident reports and should be required. The officer's greatest responsibility at an accident is for safety at the scene, not describing the accident scene."
"I feel that its use takes longer to establish a precise location of the crash, but we need to be able to collect more accurate data on locations. This could help identify a probable area (road design) or improper safety measures for roadside obstacles."
"Not applicable at this time."

Can you foresee instances when the disparity between the visually estimated and measured distances in the previous questions would significantly affect how one evaluates the safety impacts of these various roadway features?

(3) "Absolutely: for example a specified distance from a traffic signal may or may not qualify the crash as intersection related; if the distance is measured then there is no doubt."
"Yes: when trying to plan what actions need to be taken, accurate measurements can save time, money, and help pinpoint exact problem areas; in reconstruction, accurate measurements can help locate minute details, such as gouge marks, skid marks, and scuff marks in the roadway."
"Yes, the exact distance the vehicle traveled prior to a collision or after a collision can be very critical in determining proper sight distance and vehicle stopping distance over a given segment of the roadway."
"You need a system for locating problem sites, then special crews or individuals can thoroughly study those problem sites. In depth analysis and data collection need not occur until the site has been identified as a problem."
"Depends on how large the disparity is: usually the answer is 'No'".
"Especially when you have multiple intersections within the same jurisdiction with the same numbers or when you are attempting to do analyses on long segments."
"It very well could: these distances can be critical for things like vertical and horizontal stopping sight distance, 'crossing' sight distance, passing distance, clear zone requirements, and guard rail placement."
"As a transportation planner, visual location of accidents and the frequency of similar accidents would help, when mapped, to target secondary or primary road funds for needed improvements."
"I think this is one of those situations where very accurate information and its rightful analysis have the potential to be masked by prolific data. For example, there may be a marginally bad curve or hill on a lesser primary or secondary that is also in proximity to another feature like a hidden entrance, shady spot that freezes, or similar situation that either contributes to or actually causes the accidents. The remedy could be as simple as trimming some brush, cutting a tree, or laying a slope back, but because of the location a more expensive remedy is advocated like straightening the curve or lowering the hill crest."
"Yes, it could affect the degree of corrections to pavement surface, warning devices, guardrail installations, etc."

“Yes, as [VDOT] moves toward the use of GPS, road inventory data can be specifically identified by latitude and longitude, consistent with GPS data.”

“I feel that as an investigator you can make an accurate case on a fatal crash or on a number of crashes on a piece of road as to human error or roadway design or inventory of safety features.”

“From a safety perspective, the disparity between visual estimates and measured estimates would not pose a significant problem. However, for our purposes, we would concentrate more on location specific data (i.e. road/intersection.)”

APPENDIX F: FATAL CRASHES IN ALBEMARLE COUNTY 1993-1995

The column to the far left shows the date of the crash for identification purposes. The next column entitled "Distance of Events" shows the distance over which various events transpired (e.g., if the vehicle left the roadway at point *x* and then hit a tree 200' later, then the distance of events would be 200'). This column is only an estimate. The possible crash points are those locations that might be considered to be a crash, and the visible crash factors are those items that *could* be of interest to the crash analyst.

Year	Estimate of Event Distance	Potential Crash Points and Events	Possible Causal Factors
1995	unknown	vehicle left roadway vehicle hit tree	tree
	280 ft	vehicle hit pedestrian pedestrian landed vehicle stopped	driveway and Rte 29 Rte 649 and Rte 29
	unknown	vehicle dropped off road vehicle hit embankment vehicle at rest ejected driver at rest	hillcrest where ran off road driveway embankment tree
	280 ft	vehicle left road (at left) vehicle returned to road vehicle left road (at right) vehicle hit embankment vehicle hit tree vehicle at rest	edge of roadside embankment tree
	160 to 230 ft	vehicle dropped off road vehicle 1 hit vehicle 2	veh 1 passed previous car sharp curve of roadway
	more than 65 ft (trailer length)	vehicle 1 left road vehicle 1 hit vehicle 2 final rest of either vehicle	roadway where vehicle left trailer sitting on roadside
	55 ft	vehicle dropped off road vehicle crossed median vehicle at rest	median characteristics roadside characteristics
	35 ft	vehicle 1 hit vehicle 2 vehicle 1 at rest vehicle 2 at rest	store where vehicle was trying to turn
	unknown	vehicle left road vehicle hit tree	embankment tree driveway
	85 ft	vehicle hit pedestrian vehicle skid vehicle at rest	lane transition intersection Rte 29/Proffitt
	350 ft	vehicle left road (at right) vehicle hit guardrail vehicle left road (at left) vehicle hit pole	guardrail roadside where vehicle left pole driveway
	115 ft	vehicle crossed yellow line vehicle hit guardrail vehicle at rest	intersection Rte 20/Rte 816 guardrail embankment
	120 ft	vehicle left road (at right) vehicle left road (at left) vehicle hit stone pillar	curvature of road stone pillar
	20 ft ?	point of impact vehicle 1 at rest vehicle 2 at rest	embankment ? possibly driveway 150 ft away

	55 ft	vehicle 1 crossed median vehicle 1 hit vehicle 2 vehicle 1 at rest vehicle 2 at rest	
	300 ft	vehicle left road (at right) vehicle crossed median vehicle hit pedestrian pedestrian at rest vehicle at rest	intersection Rte. 29/Moreland pedestrian location median transition curvature of road
	20 ft	vehicle 1 hit vehicle 2	intersection Rte 250/Rte 738
	unknown	vehicle left road (at right) vehicle hit trees vehicle at rest	curvature of road trees
1994	20 ft	vehicle 1 began a turn vehicle 1 hit vehicle 2	intersection
	unknown	vehicle 1 hit vehicle 2	intersection with private driveway
	25 ft	vehicle 1 hit vehicle 2	
	80 ft	vehicle 1 hit vehicle 2 (length of tractor trailer and car causes variation)	intersection Rte 29/ Rte 851, 600 ft away
	much more than 50 ft, but amount not shown	vehicle l left road (at right) vehicle 1 on road (at right) vehicle 1 hit vehicle 2 vehicle 1 at rest vehicle 2 at rest	soft shoulder embankment
	unknown	vehicle 1 hit vehicle 2 vehicle 1 at rest vehicle 2 at rest	intersection Rte 250/I-64 ramp
	0-435 ft	vehicle 1 hit vehicle 2 vehicles at rest	intersection (although there is single point of impact, it is different from where vehicles are at rest)
	400 ft	vehicle left road (at right) vehicle left road (at left) vehicle at rest driver at rest	curve of road
	130 ft	vehicle began skid vehicle left road vehicle hit tree	curve of road intersection
	150 ft	vehicle hit pole as it left road vehicle hit tree vehicle at rest	curve pole and driveway tree
	135 ft	vehicle left road (at right) vehicle left road (at left) vehicle hit tree	curve of road tree
	135 ft at least	vehicle left road vehicle hit tree	tree
1993	unknown	vehicle left road vehicle at rest driver at rest	curve of road tree
	unknown	vehicle 1 hit vehicle 2 vehicle 1 hit vehicle 3 vehicles 1, 2, 3 at rest	(crash occurred on bypass)

	unknown	vehicle 1 left road (at right) vehicle 1 returned to road vehicle 1 crossed yellow line vehicle 1 hit vehicle 2	curve of road prior to crash
	unknown	vehicle crossed yellow line vehicle left road completely vehicle hit tree	curve of road tree
	230 ft	vehicle 1 left road (at right) vehicle 1 crossed yellow line vehicle 1 hit vehicle 2 vehicles 1 and 2 at rest	
	20 ft as a guess	pedestrians 1 and 2 at rest (train hit pedestrians on track)	intersection Rte 602/track intersection Rte 602/Rte 626
	285 ft	vehicle left road at right vehicle left road at left vehicle left road at right vehicle at rest	guardrail embankment
	unknown	vehicle hit pedestrian pedestrian at rest vehicle at rest	2 driveways on Rte 660
	160 ft	pedestrians 1 and 2 at rest (train hit pedestrians on track)	crosswalk across track
	220 ft	vehicle left road (at left) driver ejected vehicle on road at rest	guardrail