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Methodology for Reconciliation of Different Forms of Electronic Data in Vehicle Collision Reconstruction

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Abstract

Collision analysis utilizing electronic data recorders, videos, traffic signal timing data, and other electronic records adds valuable input but can be a challenge to tie together due to the lack of a finite time stamp or common recording rate. However, overlapping data streams that have a common point-in-time identifier can be resolved. A strategic approach was developed by the author for unifying and validating the vehicle positions and time-distance reconstruction. The method outlines the steps for establishing known data points, forming a common time line, identifying overlapping information, and linking together independent records. A case study demonstrates a crash at a traffic signal-controlled intersection in which each vehicle entered on their respective green lights without conflict; however, the collision still occurred. The crash reconstruction will highlight driver options and demonstrate the value of combining multiple data streams into one time line.

Keywords

Collision, accident reconstruction, electronic data, crash event data, event data recorder, EDR, CDR, airbag, black box, traffic signal timing, video, surveillance, camera match, time distance, vehicle, tractor/trailer, motion capture

Background

A collision occurred at a traffic signal-controlled intersection in the western suburbs of the greater Miami, Florida metro area. Both vehicles reported having a green light upon entry, and no malfunction of the signal occurred.

An SUV (Vehicle A), traveling northbound across the main boulevard, entered the intersection on a green traffic signal, but was delayed by a left-turning vehicle coming from the opposite side of the intersection. After proceeding across the intersection to the north, a collision occurred. A sedan (Vehicle B), traveling westbound, entered the intersection on a green traffic signal, and struck the front right side of the SUV. The collision fatally injured an occupant in the sedan. A surveillance video was recovered showing a portion of the incident; however, the traffic control signals were not visible. The road surface was dry, it was daylight but overcast, and the posted speed limit for through traffic was 45 mph.

Motivation

A dispute regarding right of way and failure to yield ensued due to a lack of clarity regarding the collision timing and the specific sequence of the traffic light at the time of the collision, since each vehicle reported having a green light upon entry — and no malfunction of the traffic signal occurred.

The initial task was to collect evidence, orient the vehicles at impact and final rest, and determine how the collision occurred. Airbag control module (ACM) data was collected and evaluated for the crash. Crash reconstruction analysis confirmed the ACM recorded speeds. Diagrams stepping back in time several seconds just prior to the collision were created to establish the positions of the vehicle on scaled diagrams. Since this incident was partially captured on surveillance video, synchronizing the video to the ACM data — and matching the vehicle motion to the traffic signal timing — became one of the more significant tasks.

A generalized protocol for reconciliation of these different types of electronic data will be presented in this paper as a result of the efforts in this reconstruction. The order of evaluating or anchoring the known data points may be incident specific. However, the author will demonstrate a logical progression, establishing known positions, and working backward in time to determine unanswered questions.

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The methodology follows a similar pattern to the typical accident reconstruction teaching. Due to the desire of blocks of time and distance data from different sources needing to be synchronized together, the author hopes that this document can be used to simplify the process and reduce the number of iterations required.

It is important to keep in mind that a forensic investigation/analysis of any incident is likely to be a complex and scientific endeavor. Therefore, the methodology of such an endeavor must include the comprehensive, objective, and accurate compilation/analysis of the available data. Both the quality and quantity of data will vary depending on the situation and should be considered accordingly.

Accident Site

The accident site was a six-lane, boulevard-style street with three through lanes of traffic in each direction. The opposing lanes were separated by a raised median covered with grass and trees. At the intersection, east- and westbound traffic utilized dedicated left turn lanes to allow traffic to cross when permitted. Westbound traffic also had a dedicated right turn lane servicing a gated community to the north. **Figure 1** shows an aerial photograph of the accident site. For orientation purposes, north is at the top.

Intersection design was typical for south Florida suburban areas[1]. The primary boulevard continued across the developed residential area. The speed limit was posted as 45 mph, and it was clear, dry, and daylight with no environmental factors contributing to the accident. The cross-street services private gated residential communities to the north and south.

A guard shack to the south of the intersection, shown in **Figure 2**, was equipped with a security camera that recorded the SUV leaving the property and a partial view of the crash. The surveillance camera video was recorded at 30 frames per second (fps); however, the orientation and field of view limited the useful images — as the crash occurred at the top edge of the frames, and Vehicle B only entered into view just before the collision.

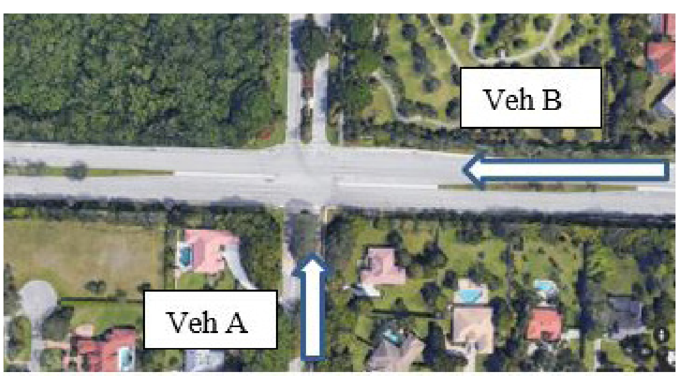

Figure 1
Google Earth image of the intersection.

Vehicle A (SUV)

Vehicle A was a 2010 four-door SUV (**Figure 3**). The curb weight was 5,983 lb. The SUV was powered by a 5.7-liter V8 gasoline engine. It was equipped with an ACM that stores crash data during an impact. Data was downloaded and analyzed showing that the speed at impact was 20 mph — and that the car was accelerating at the time of collision.

Event data recorder (EDR) data imaged from Vehicle A shown in **Figure 4** helped establish the pre-impact position, speed, and driver inputs.

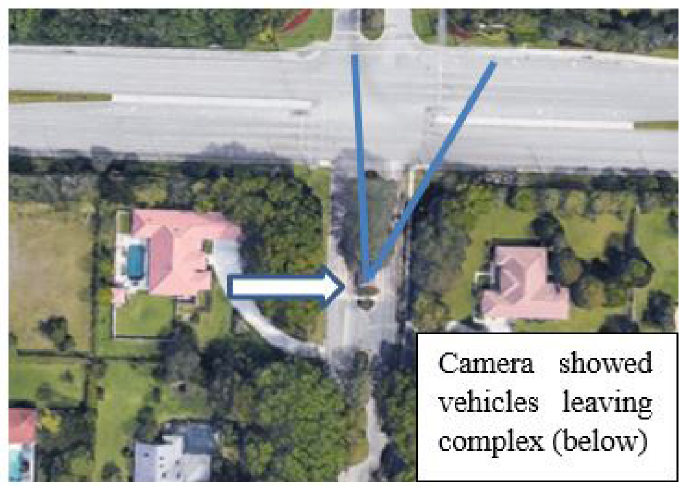

Figure 2
Google Earth image of locating the guard house and security camera.

Figure 3
Damage to right side front of Vehicle A was consistent with the EDR data.

Pre-Crash Data -5 to 0 seconds (Most Recent Frontal/Rear Event, TRG 2)						
Time (sec)	-4.3	-3.3	-2.3	-1.3	-0.3	0 (TRG)
Vehicle speed (mph [km/h])	1.2^{2}	1.2^{2}	6.2^{10}	12.4^{20}	19.9^{32}	19.9^{32}
Brake switch	ON	OFF	OFF	OFF	OFF	OFF
Accelerator rate (V)	0.78	1.29	1.33	1.48	0.78	0.78
Engine rpm (RPM)	400	400	1.200	2,400	3,200	3,200
Pre-crash data status*	Valid	Valid	Valid	Valid	Valid	Valid

* Invalid may be set for M/T vehicle

Figure 4
Vehicle A EDR pre-crash data.

Vehicle B (sedan) was a 2016 passenger car (**Figure 5**). The curb weight was 2,555 lb. The sedan was powered by a 1.6-liter four-cylinder gasoline engine. It was equipped with an ACM that stores crash data during an impact. Data was downloaded and analyzed showing that the speed at impact was 37 mph — and that the car had been accelerating prior to the collision.

EDR data imaged from Vehicle B shown in **Figure 6** helped establish the pre-impact position, speed, and driver inputs.

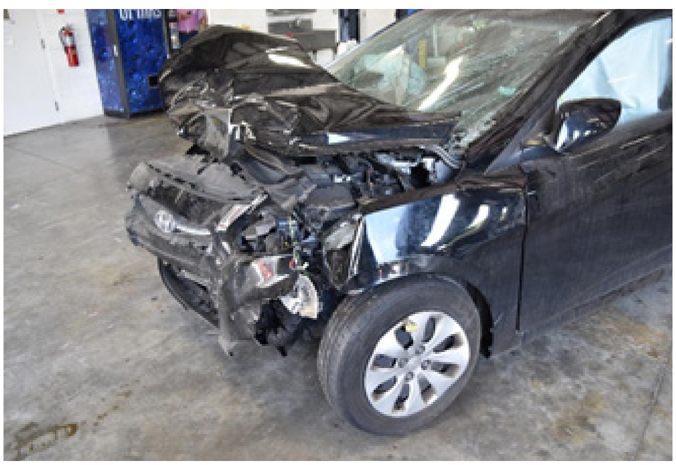

Figure 5
Damage to left front of Vehicle B was consistent with the EDR data.

The first step in evaluating the traffic signal sequencing was determining whether the intersection in question participated in the Federal Highway Administration's Automated Traffic Signal Performance Measures (ATSPM) program. Intersections for which high-resolution ATSPM data is recorded allow for analysis of time-stamped status data for every moment of their operation[2].

It should be noted that analysis of ATSPM data would still require the reconciliation of the signal status timestamps to the recovered vehicle ACM and ECM data in addition to any reconstructed vehicle positional data.

Unfortunately, it was determined that no high-resolution data had been recorded for the subject intersection. Therefore, the traffic signal sequencing and timing was analyzed via a review of the traffic signal programming. Of particular utility was analysis of the time-based programming for the intersection[3]. This analysis resulted in a data set indicating minimum and maximum timings for signals in each direction based on vehicle demand, in addition to the sequencing of the various signals.

A review of the programmed time and sequency for the traffic in each direction enabled a determination of how long the green-red signal condition existed relative to the determined vehicle positions. By reviewing other

Time (sec)	Vehicle Speed (kph)	Engine RPM (RPM)	Engine Throttle (%)	Acceleration Pedal (%)	Service Brake (on/off)	ABS Activity (on/off)	Stability Control (on/off/engaged)	Steering Input (degree)
-5.0	66 (41 mph)	1300	5	0	ON	OFF	ON	0
-4.5	64 (39.8 mph)	1200	4	0	ON	OFF	ON	0
-4.0	62 (38.5 mph)	900	4	0	ON	OFF	ON	0
-3.5	60 (37.3 mph)	1000	5	0	ON	OFF	ON	0
-3.0	58 (36.0 mph)	1100	5	0	OFF	OFF	ON	-5
-2.5	57 (35.4 mph)	1900	29	25	OFF	OFF	ON	-5
-2.0	57 (35.4 mph)	2200	57	27	OFF	OFF	ON	0
-1.5	58 (36.0 mph)	2200	59	27	OFF	OFF	ON	0
-1.0	59 (36.7 mph)	2200	59	30	OFF	OFF	ON	0
-0.5	60 (37.3 mph)	2400	62	33	OFF	OFF	ON	0
0.0	59 (36.7 mph)	2100	8	0	ON	OFF	ON	-40

Figure 6
Vehicle B EDR pre-crash data.

non-related traffic also visible in the surveillance video and coordinating the analyses helped refine the change in signal timing.

Reconstruction Outline

The next phase was the collision reconstruction. The first step was to establish known facts, and then to evaluate the working theory regarding signal timing to determine the traffic control conditions — and if the working theory was consistent with the evidence.

The reconstruction included establishing known data points based on the data collected during the accident investigation, which included a detailed analysis of the physical evidence, roadway geometry, and specific vehicle dimensions and geometry, using high-definition three-dimensional (3D) laser scanning and unmanned aerial vehicle (UAV) aerial imagery. The physical evidence and area of impact were identified and highlighted on an aerial image of the intersection (**Figure 7**).

Each vehicle recorded crash data in the airbag control modules. However, few vehicles time and date stamp EDR data; in this case, neither did. Five seconds of pre-crash data is recorded but must be reconciled with the other information. In addition, the consistency of the recorded data — and the speeds, in particular — only need to be verified by traditional accident reconstruction techniques.

The authors believe it can be potentially troublesome to accept and use EDR data without confirmation and/or verification of consistency with the given collision evidence.

Figure 7
UAV aerial image of the intersection showing physical evidence.

Conservation of linear momentum[4,5,6] crash simulation programs[7,8] would confirm speeds based on the documented area of impact and final rest position for each vehicle. Another option, which could be employed if the impact and final rest positions were unknown, would be a camera-matching technique using the security camera video.

Camera-matching is a close-range photogrammetry analysis of 2D imagery. This process utilizes 3D data of the scene to match the perspective of 2D imagery in 3D space, and it allows for spatial analysis of objects, features, or people in videos and photographs[7]. Computer software imports the 2D imagery and 3D data into one digital environment where common points between the two data sets are identified. The software calculates the relative location of the points in 3D space compared to their corresponding location in the 2D imagery and determines the necessary camera location/settings to create a replica of the camera in 3D space. The result is a virtual camera in the 3D space of the laser scan data that matches the real-world camera that captured the imagery. When viewed through this virtual camera, the 3D data is aligned to the imagery, allowing for accurate placement of additional 3D objects.

In vehicle accident reconstruction, camera-matching can be used to track the position of vehicles over time. With the 3D scan data aligned to video of an accident, 3D vehicle models are constrained to the ground plane established with the laser scan data and then moved in 3D space to match the position within the frame of the 2D imagery. Physical evidence, EDR data, and other information can be incorporated into positioning of the 3D vehicle models to improve accuracy. Positioning vehicles periodically over time results in a 3D animation of the accident that can be analyzed as part of an accident reconstruction as well as providing demonstratives for visualizing the motion of the objects.

The accuracy of a camera-match is a function of the quality of the site 3D data as well as the quality and characteristics of the 2D imagery. The lens distortion was corrected, and camera orientation was accounted for using commercially available software and commonly accepted techniques. The orientation and field of view limitations of the security video in this matter made an accurate determination of the speeds solely through camera-matching challenging and less useful in this particular case. The specifics of the speed determination are not the focus of this manuscript; therefore, the author proposes that the EDR data was determined to be accurate, and those recorded speeds will be used.

Multiple graphics and 3D digital images were used to demonstrate the findings of the accident reconstruction and illustrate the vehicle location at specific timing, visibility, driver's view, including the ability to see the other vehicle and other factors that led to this event. Production of these graphics provides an opportunity to double check the analysis. Some will be used throughout this paper to assist with explanation. **Figures 3** through **10** are one example in 2-D form of the graphics used to illustrate and confirm the specific vehicle locations, orientations, and line-of-sight for the drivers.

Traffic signal timing plans were provided by the local Department of Transportation and evaluated. Analysis of the time-based programming for the intersection provided minimum and maximum signal timings in each direction and the sequencing of the various signals. Of interest in this incident was the introduction and time of the northbound and southbound green ball with permissive (but not protected) left turn as well as the transition to and conclusion of the red signal.

A permissive left turn is a left turn that occurs during a solid green indication (no turn arrow) and requires the driver to determine a safe turning window between opposing thru-traffic. The evaluation of traffic light timing accidents (and who had the red light) are always difficult to evaluate absent independent information or specific timing, which can be related to the light condition. Techniques for determining speeds and matching the video recorded motion with the traffic signal phase was outlined by Couture[8]. He established a guideline of steps to be followed for a video analysis as shown below.

Forensic Engineering Analysis and Collision Evaluation

The collision evaluation included a review of the following material:

1. Police traffic crash report and police investigation material.

2. Scene photographs.

3. Witness statements and depositions.

4. Surveillance video from a security entrance near the intersection.

The investigation tasks included:

1. Documented the site with photographs and video at ground level and from the air.

2. Documented the path and typical speed of traffic on this road under similar condition with aerial video.

3. Documented the roadway with HD 3D laser scans.

4. Examined, photographed, and measured the SUV and the sedan.

5. Documented the SUV and the sedan with HD 3D laser scans.

6. Imaged the crash data from the SUV and the sedan's ACM.

7. Reviewed and evaluated the traffic signal timing plans for the intersection.

Step 1	Create a spreadsheet with signal color by road, validity, time, observations by road with position in frame.
Step 2	Set one interval per row, matching seconds (or ticks).
Step 3	Observe the video, and note the number of vehicles, actions, and positions for each interval.
Step 4	Code the range of interest; then add the signal phase timing to the spreadsheet.
Step 5	Compare the activities and observations to the phase, and rank according to rules.
Step 6	Iterate the placement of phases until a validity acceptance criteria is met.
Step 7	Verify the timing assumptions by validating the actions with an external source (SAE papers, data from third parties).
Step 8	Set the signal phase sequence, and tie it to the observations.

Couture also addressed "analysis of indirect video," some of which can be employed in this case example — the premise being that vehicles proceed through the intersection on a green light, and there is a high probability of vehicles stopping for a red light.

Analytical Method

The forensic engineering evaluation of the pre-collision events utilized event data from ACM, computer -aided drawing and design (CADD), video analysis, and traffic signal timing evaluation. The graphical, geometric, and analytical methods that were applied in the analysis included the following:

1. Created 2D and 3D CADD models based on the photographs, measurements, and laser scans of the vehicles to evaluate crash and pre-crash time and distance positions.

2. Created digital model of the site based on measurements, laser scans, and mapping with aerial photos.

3. Determined positions of vehicles on the road along the travel path leading up to impact. For this case, the team used ACM data and physical evidence at the site.

4. Exemplar vehicle was used to measure the roadway drag factor at the site, under similar conditions, utilizing techniques described in SAE J2505.[9]

5. Synchronized the vehicle movements with one another, based on the surveillance video and EDR data.

6. Based on the traffic signal timings and coordination programming, determined the traffic signal sequence and range of potential timings.

7. Synchronized the traffic signal timing to the vehicle movements. For the example presented, additional video footage was acquired, and the motion of traffic through the intersection on multiple traffic signal cycles was utilized. Increasing the number of samples can reduce the variability associated with the driver reaction time[10,11]. However, when less video timing is available, initiation of a green light precedes stopped vehicle motion. Some perception-response time needs to be accounted for prior to the observed vehicle acceleration[12]. For this incident, a 1.5-second PRT was used for evaluating possible avoidance scenarios. The EDR data established when driver input changed and was incorporated into the overall reconstruction analysis. Caution should be used when determining perception-response and stopping due to a yellow or red signal, as decision and braking time vary more widely than the acceleration light from a stopped position when given a green light.

8. Additional traffic and additional video can allow more refinement of the sequence for the traffic signal timing, which improves the synchronization with other data sources.

Note: Some traffic signal plans allow for extensions or triggered changes during specific times or days. Careful evaluation of the signal timing plan should be used so as not to incorrectly synchronize a non-standard sequence.

Results

The resulting time and distance position, visibility and key position are best described showing graphical recreation of the scenario. **Figures 8** through **15** demonstrate the approach of each vehicle. Vehicle A approach is from the bottom of the image, and Vehicle B enters from the right — but not until the fourth image. The last image shows the impact.

Summary of the Methodology

A summary of the key elements is provided to assist the reader when synchronizing data in an similar incident.

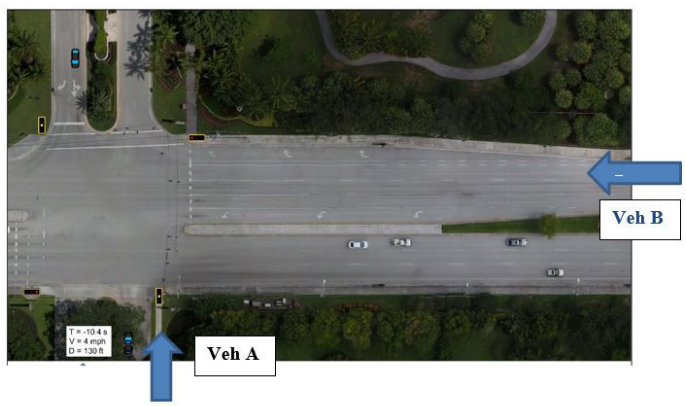

Figure 8
Aerial image showing time and distance position and traffic signal state.

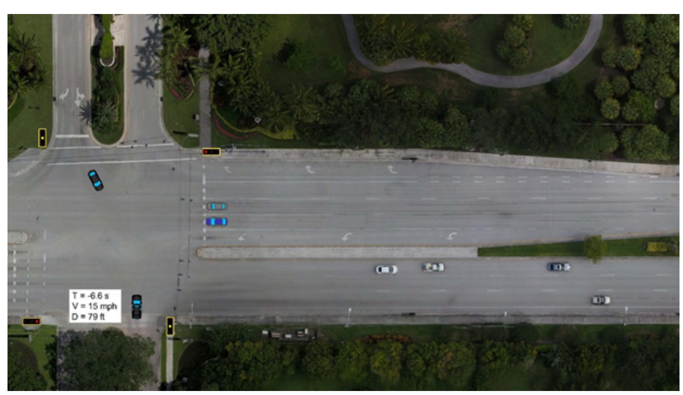

Figure 9
Aerial image showing time and distance position and traffic signal state.

- Determine vehicle speeds and impact positions using generally accepted accident reconstruction methods.

- Identify known time and distance relationships in order to establish relative vehicle positions. Note: This will likely not include the timing aspect of yet-to-be-determined blocks such as traffic signal sequence.

- Fix known position with physical evidence, such as point of impact. If the area of impact is not

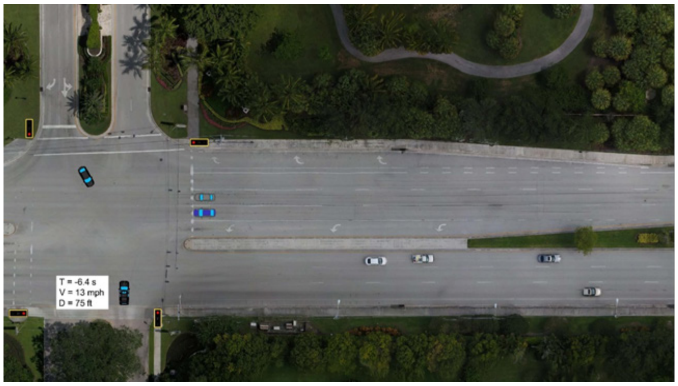

Figure 10
Aerial image showing time and distance position and traffic signal state.

Figure 11
Aerial image showing time and distance position and traffic signal state.

Figure 12
Aerial image showing time and distance position and traffic signal state.

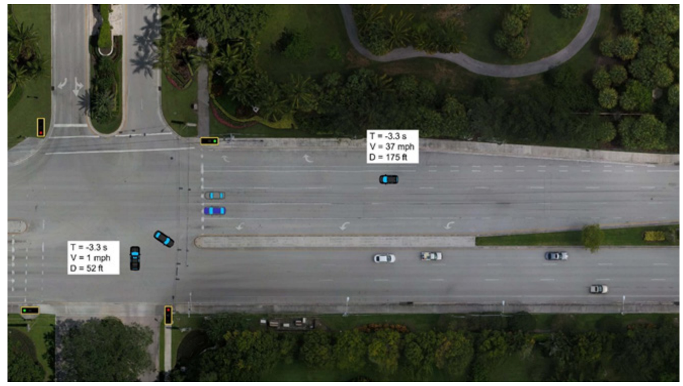

Figure 13
Aerial image showing time and distance position and traffic signal state.

Figure 14
Aerial image showing time and distance position and traffic signal state.

Figure 15
Aerial image showing time and distance position and traffic signal state.

known, the area of rest can be used. Reconstruction of the post impact motion to determine an area of impact will introduce error, which should be quantified. Bracketing[4,5,6] accident simulations[13,14] Monte Carlo method or uncertainty analysis[15,16] can be used to evaluate the accuracy of the reconstruction analysis. Camera matching can also be used to verify vehicle position or to augment the determined position, speed, or motion of objects captured on video[16].

- Don't try to "fit" positions based on other evidence, such as witness statements or narratives in reports until all known physical evidence or established data has been exhausted. Later, if a "fit" must be used, disclose the extrapolation and uncertainty associated with placement.

- Determine which "known positions" can be tied to electronic data. Anchor time and distance data to the scene data with the best known or established point geometrically and in time. In this incident, area of impact was established by physical evidence and allowed a convenient anchor for both geometry and time.

- Determine or establish any additional vehicle positions that are consistent with the other data. This may include other objects, actions, or non-involved vehicles.

- When a precise anchor between vehicle data blocks is unknown, develop time and distance chart for ACM/EDR independent of other input. The data is a record of the vehicle's sensors and should be evaluated or verified independent of scene and other inputs until a known site data point, physical evidence, or additional information is established.

- Asynchronism of ACM/EDR data and data being reported at different frequencies is common and should be evaluated carefully. Additional caution is warranted when combining EDR data due to this factor.

- Look for overlapping electronic, such as a known time or known position, which can be used to confirm the theory regarding using physical evidence or reconstructed positions.

- Identify and combine common/overlapping positions in the time domain.

- Synchronization of video may require extra video records of traffic not related to the incident. Note: It may be helpful to observe additional video during the time preceding this event. Viewing non-related traffic movements through the intersection, stopping and starting at the signal can be used to evaluate the signal sequence without viewing the lights. It is necessary to account for a potential lack of precision, but this technique may be helpful to gain an understanding of the traffic signal timing related to the surveillance video.

- Reconstruct any remaining positions, and fill in time and distance as needed while recognizing these are not known data points, but rather reconstructed positions.

- Check for consistency.

Summary

The detailed forensic engineering evaluation and reconstruction of this collision event created the situation prompting the methodology for reconciliation of different forms of electronic data to be established. Utilizing the methodology, the following conclusions were determined for this incident:

- Vehicle A entered the intersection on a green/yellow light, approximately 90 feet from the collision.

- Vehicle B entered the intersection on a green light, approximately 50 feet from the collision.

- Due to a delay, Vehicle A had not cleared the intersection prior to the arrival of Vehicle B, and a collision occurred in the right westbound lane.

- Traffic signal sequence was determined using traffic flow and video analysis, combined with an analysis of programmed time-of-day programming for the intersection.

- Synchronization of traffic signal timing and ACM data as well as surveillance video was accomplished by a sequential systematic matching of known data points.

Conclusion

Arising from this unfortunate traffic accident was the development of a methodology for synchronizing electronic data from multiple sources internal and external to the involved vehicles. A strategic approach was developed by the author for unifying and validating the vehicle positions and time-distance reconstruction. The method provides systematic steps for establishing known data points, forming a common time line, identifying overlapping information, and linking together independent records. The case study demonstrates the value of combining multiple data streams into one time line, thus enabling a clear understanding of how the event occurred.

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