Police officers and accident reconstruction practitioners often use digital photography as a means of determining the root cause of an incident. In order to extend the use of such photography, investigators have recently turned to Close-Range Photogrammetry (CRP) techniques to derive accurate three-dimensional (3D) measurements from photos taken shortly after a crash or crime scene event. CRP is a proven measurement technique that extracts 3D information from multiple overlapping 2D photographic images. This article reports on the use of photogrammetry in an investigation of a fatality resulting from a three-car traffic incident. During a street race between two cars driven by teenagers, one of the drivers hit a third vehicle in which a passenger was killed. In the subsequent accident reconstruction investigation, which utilized the “Speed Triangle” (Momentum, Energy and the Power Train Control Module (PCM)) concept, CRP proved to be a valuable integral component in the calculations of vehicle speed, as well as providing a fast and accurate means to map the crash scene.

The crash:
Kathleen Avenue is a residential street in downtown Coeur d'Alene, Idaho. It has two lanes in each direction and a dedicated center-turn lane. The street travels east-west, with an elementary school at the west end and a “charter” school at the east. Two teenage drivers entered Kathleen Avenue from the west end. Driver 1, in a 2005 Subaru Impreza WRX STi, was adjacent to the elementary school when a 2006 Mustang with Driver 2 at the wheel pulled up alongside and revved his engine. Driver 1 revved his engine in response and the race was on. The two cars sped eastbound along Kathleen Avenue, fast approaching the intersection with Howard Street.
At that same time moment, a 1987 Chevrolet Caprice under the control of Driver 3 was entering Kathleen Ave from Howard St. The Mustang slammed into the Caprice near the driver’s side ‘B’ pillar, shattering Driver 3’s pelvis and killing his 14-year old son who was seated in the right rear of the Caprice. The Impreza swerved to avoid the collision and Driver 1 lost control, quickly transitioning into a broad slide, leaving the roadway and rolling to the vehicle’s final rest position more than 100 yards beyond the point of impact.

The police investigation:

The iWitness™ photogrammetry software system, ([www.iwitnessphoto.com](http://www.iwitnessphoto.com)) combined with a Nikon DSLR camera, was used to map the crash scene, which extended over 403 feet.

Due to the length of the scene, it proved easier to perform two separate “image-based measurement networks” that were later ‘stitched’ together within the iWitness software to form a unified reference coordinate framework to produce an accurate scaled diagram in which the crash evidence was recorded. The total time to process this scene using photogrammetry, or the ‘digital camera approach’, was approximately 40 minutes. The iWitness software was employed to generate a 3D model and measure the scene, with the scaled 3D model in DXF format being subsequently exported to the Crash Zone diagramming software.
It took approximately 3 hours of PC work at the office to fully accomplish the photogrammetric mapping and diagramming using iWitness, which was also employed to develop damage profiles for both the Caprice and Mustang.

Through use of a **Vericom VC2000** accelerometer, the drag factor at the scene was determined as being 0.77.

From the iWitness image-based measurement data, and the subsequent diagramming, the following was determined:

- The Mustang left 73.8 feet of visible pre-collision skid before it struck the Caprice and it then traveled a further 60.6 feet, while rotating through 70 degrees, before coming to rest.
- The Caprice was struck behind its center of gravity and was spun rapidly through 242 degrees, coming to rest 41.0 feet beyond the point of impact.
- The Impreza started its critical speed yaw just east of the intersection, first sliding into the oncoming travel lanes and then re-entering the eastbound lanes and leaving the roadway. By plotting the Impreza’s center of mass path of travel over the first 68 feet of its yaw, the course of its center of mass was shown to have inscribed an arc with a radius of 572 feet.

Concerning the Subaru, its speed was calculated using the relationship: $$ S = 3.87 \sqrt{R(f \pm e)}.$$ Here, since the roadway was level, this became $$ S = 3.87 \sqrt{(572)(.77)} = 81 \text{ mph}.$$ Since there were impact and departure angles as well as crush data, a two-pronged approach to speed calculations were used. David Thornburg’s Excel Spreadsheet “**Equation Calculator**” was first employed to determine post collision speeds for both cars. The effective drag factor for each vehicle was determined based upon the Regression Equations presented by Dr. Gordon Bigg P.E. at the 2003 IPTM Special Problems event, this approach having been confirmed in research by John Daily. The investigative was based upon evidence that the Caprice had two wheels locked, while the Mustang had no wheels locked. From the work of Bigg and Daily, we have $$ \rho = \frac{\theta}{d} $$ (where \( \theta \) = the total heading change in degrees and \( d \) = the total distance traveled by the center of mass).

For a vehicle with engine braking only (the Mustang) we have: $$ \eta = -0.0079 \rho^2 + 0.0764 \rho + 0.3418 $$ and for a vehicle with two locked wheels (the Caprice) we have: $$ \eta = -0.0046 \rho^2 + 0.0182 \rho + 0.8003.$$ These expressions are used in determining the applied drag factor, \( f = \mu \eta \). Hence, the two applied drag factors would be \( f_{\text{Mustang}} = (0.77)(0.420) = 0.323 \) and \( f_{\text{Caprice}} = (0.77)(0.747) = 0.575 \).

Application of these rotational drag factors to the post collision distances, along with utilization of the slide-to-stop formula $$ S = \sqrt{30df} $$, yielded post collision speeds of approximately 24 mph for the Mustang and 26 mph for the Caprice. The scale scene diagram and crush profiles for the Mustang and the Caprice (all generated from the CRP projects; both at the scene and afterwards) were then used to
determine approach and departure angles for both vehicles. The Mustang was set up as the “bullet” car with approach and departure angles of 0°. The Caprice then had an approach angle of 104° and a departure angle of 12°. The vehicles were weighted after collision, yielding weights of 3555 lbs. for the Mustang and 3950 lbs. for the Caprice. Through use of a momentum solution, this yielded an impact speed of 54 mph for the Mustang and 5 mph for the Caprice. It also indicated a $\Delta v$ of 29.8 mph for the Mustang and 26.8 mph for the Caprice.

In evaluating this crash from an energy perspective, it was discovered that there were no stiffness coefficient values available for a side impact on a 1987 Chevrolet Caprice. Here, impact forces based upon the principles espoused in Nathan Shigemura and Andrew Rich’s paper, Balancing Collision Forces in Crush/Energy Analyses (2007) were balanced. Through use of the CRP measurements of each vehicle, the crush profiles were plotted against exemplar vehicles.
The calculated stiffness coefficients for the Chevrolet and stiffness values from NHTSA testing of the Mustang were then applied to calculate a collision speed of 57 mph for the Mustang and 5 mph for the Caprice. This analysis yielded a Δv of 33.2 mph for the Mustang and 29.9 mph for the Caprice.

The Mustang was equipped with ABS brakes and all four wheels were actively braking before collision. Resulting marking on the road was very faint; but it could be established that the Mustang left 73.8 feet of visible pre-collision skid. Application of slide-to-stop analysis to this braking maneuver indicated that the Mustang lost at least 41.3 mph. This pre-collision speed loss, along with the impact speeds calculated from the Momentum analysis and Energy analysis above, was used to determine pre-braking speeds for the Mustang of:

\[ S_{\text{MOMENTUM}} = \sqrt{S_1^2 + S_2^2} = \sqrt{41.3^2 + 54^2} = 67.9 \text{mph} \]

and

\[ S_{\text{ENERGY}} = \sqrt{41.3^2 + 57^2} = 70.4 \text{mph} \]

The airbag control modules from the Subaru and the Mustang, as well as the Mustang’s Powertrain Control Module, were also analyzed. No imaging data was available for the Subaru (either then or now). In 2006, there was no support for any of the Ford modules; however Bosch released the software and hardware for the Mustang in late 2007. David Thornburg analyzed the data from the PCM and used C. Gregory Russell’s CSV Pro spreadsheet to graphically represent the image.

The Mustang was not using “stock” wheels/tires and there was no evidence the speedometer had been re-calibrated to the aftermarket equipment. Since the actual wheels and tires were slightly smaller in diameter, it was determined that the actual speeds would be approximately 4.8% lower than what was represented here. Hence, the following speeds from the PCM data were established:
Now the “Triangle” is complete. Looking at the calculated speeds from the momentum and energy analyses and comparing them to the PCM data, we have:

<table>
<thead>
<tr>
<th>MUSTANG</th>
<th>PRE-BRAKING SPEED</th>
<th>IMPACT SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum</td>
<td>68 mph</td>
<td>54 mph</td>
</tr>
<tr>
<td>Energy</td>
<td>70 mph</td>
<td>57 mph</td>
</tr>
<tr>
<td>PCM</td>
<td>78 mph</td>
<td>62 mph</td>
</tr>
<tr>
<td>Average</td>
<td>72 mph</td>
<td>58 mph</td>
</tr>
<tr>
<td>σ</td>
<td>± 4.29 mph</td>
<td>± 3.74 mph</td>
</tr>
</tbody>
</table>

The higher pre-braking speed is easily explained, since the faint nature of the ABS marks would lead to an under-reporting of the skid distance and hence a lower calculated speed. Given the PCM data is reported every 0.2 seconds, the reported speeds were integrated to calculate the approximate distance the Ford Mustang traveled before impact. This total distance was around 1,700 feet or nearly one-third of a mile. This helped placed the Mustang along the roadway as it traveled and was consistent with several of the witness statements.

Conclusion:

Different technologies were used to determine the root cause of a vehicular homicide in this case. CRP allowed accurate and rapid 3D measurement of both the crash scene and vehicle profiles, providing the needed distances to complete the “Speed Triangle”. The close correlation between the calculated collision speeds using momentum, energy and the PCM image is inescapable. Additionally, the PCM data clearly showed the “racing” trend in acceleration and throttle, which mirrored witness testimonies at trial. Furthermore, comparing the regression analysis for post-collision rotational speeds against the recorded speed for the Mustang showed a negligible difference (24 mph for both). Also, the Subaru’s speed was calculated at 81 mph from CRP measurements and the applied “critical speed” calculation. This correlates well with the Mustang’s corrected PCM speed of 78 mph at the beginning of braking. Finally, by applying and evaluating all of today’s available techniques and technologies in this crash, an accurate reconstruction was obtained and the three analyses formed a strong “Speed Triangle”.

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