Video Collision Reconstruction Using Physical Evidence

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The reconstruction of a motor vehicle collision is often achieved through investigation and interpretation of the physical evidence left in the aftermath of the collision. Such evidence can be in the form of tire marks and gouges at the collision scene, the structural damage to the vehicles, and occupant contacts with the vehicle interior. Collisions can be extremely complex and yet it is often necessary for investigators to explain the precise nature of the collision events to individuals who have little expertise in interpreting physical evidence. Historically reconstructions have been illustrated by means of schematic diagrams to provide a static representation of collision events. With the availability of reasonably priced videocassette recording equipment, it is now possible for investigators to readily adapt animation techniques normally used by film makers to the field of collision reconstruction. Scale diagrams of the involved vehicles are overlaid on a scale diagram of the collision scene and the reconstructed motion of the vehicles is videotaped by using a cutout animation technique. The resulting visual presentation provides an excellent means of communicating complex events to nonspecialists. The method is demonstrated by the reconstruction of a multiple-vehicle, multiple-impact collision.

The basis for producing a videotape of animated vehicle movements is a detailed documentation of all the collision-related physical evidence. The investigator must inspect the vehicles involved and the collision scene as soon as possible, because some types of physical evidence disappear quite quickly. The precise locations of various portions of evidence should be documented extensively. The vehicles should be measured to determine their damaged profiles. Sample vehicles may be used to obtain the original dimensions. These points will be expanded later in the discussion.

COLLISION RECONSTRUCTION

Documenting the location of physical evidence found at the collision scene is relatively straightforward. Various techniques may be utilized to make the required measurements (*1*, pp. 451–462). The method favored by the authors is the use of a rectangular coordinate system, because simple measuring tools can be utilized very effectively (2, pp. 335–336). The process involves making a series of careful and detailed measurements at the collision scene. Often, some measure of skill is involved in determining the scene evidence that is relevant to the collision being investigated.

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Various factors make accurate measurements of the damaged vehicle difficult. The vehicle will normally be measured in the field, typically in a towing compound, where the terrain may not be level. The vehicle may be so deformed that none of the original contours remain intact. Also, damage profiles at different vertical levels may be of critical importance.

A technique for obtaining measurements of the profile of a damaged area on a vehicle by using a contour gauge has been described by Tumbas (*3*). A variant of this method (*4*, pp. 352–368) is to place a reference rectangle around the entire vehicle. If practicable, the original length and width of the vehicle concerned should be used as the dimensions of the sides of the rectangle in order to provide a particularly useful reference frame. Measurements are taken from the sides of the rectangle to damaged areas of the vehicle at right angles in both the horizontal and vertical planes. Some adjustments to the vehicle or rectangle must be made where the ground or vehicle is not level or some compensation in the measurements must be made to avoid errors.

The measurements required to produce a replica of a damaged vehicle for the purposes of video recording will depend somewhat on the type of collision involved. In any reconstruction, the investigator should take a number of measurements to establish a good representation of the areas of direct damage.

An area of direct damage is a region that was in direct contact with the vehicle or object struck in the collision. Within such a region, measurements should be taken to establish the precise location of points of mutual contact, which are specific locations on one vehicle for which contact evidence can be identified on specific locations of another vehicle or object. Typically, a crease, transfer, or imprint on a vehicle is identified as originating from contact by a bumper bolt, license plate, grille, roof pillar, and so on, of another vehicle. These points must be identified in their original positions on an undamaged vehicle as well as on the damaged vehicle being measured.

Points of mutual contact that have been identified and so documented may be utilized in the animation of the collision events. The reason for moving the colliding vehicles from one position to the next during recording will be based on evidence from points of mutual contact in addition to scene evidence.

Additional measurements should be taken to document the overall shape of the damaged vehicle. As a guide it is suggested that the following be measured as providing valuable information relating to vehicle position, orientation, and motion:

1. The amount of end-shifting of the vehicle's structure;
2. The location of the corners of the hood, provided that the hood is not hanging loose;

3. The locations of the outboard surfaces of the wheel hubs;
4. The positions of the roof pillars, measured at the top (at the junction with the roof) and at the level of the base of the window glass; and
5. The locations of the ends of both front and rear bumpers.

Once detailed measurements of the vehicles and collision scene have been obtained, the next step is to produce scale diagrams of each of these items.

No ideal scale exists for all situations; it is based on the investigator's needs, which differ from case to case. When an animated videotape of collision events based on physical evidence is produced, it is desirable to choose the largest scale possible without making the subjects so big that the investigator cannot move around them.

A suggested scale is 1:10, which will produce passenger car diagrams that are 50 to 55 cm (19 to 22 in.) long. Such a scale will produce large but manageable scene diagrams for the majority of collisions. The suggested scale is also useful in that most passenger car diagrams produced to this scale will fit on two sheets of 8.5 × 11-in. paper.

With rudimentary drafting instruments (an engineer's scale, protractor, and straightedge) the investigator can construct a rectangle on the sheet of drawing paper in which he will reconstruct the dimensions of the damaged vehicle that had been measured previously. Initially, a pencil drawing of the vehicle in plan is produced.

In a similar manner the investigator draws the original shape of the same vehicle. Original measurements of the case vehicle are readily obtained by visiting a large parking lot and taking the measurements directly from a parked vehicle of the same year and model. By matching the characteristics of the Vehicle Identification Number (VIN) of the damaged and sample vehicles, the investigator can be assured that both have the same relevant body dimensions.

Once the pencil drawings of the damaged and the original vehicles have been completed, the investigator will trace the drawings onto clear plastic sheets with a set of colored marking pens. The collision scene should be drawn on a large roll, or a large sheet, of thin white paper. If large sheets are not available, smaller sheets can be taped together with transparent tape, which is not visible on the videotape. The relevant roadway markings should be drawn in pencil on this large sheet of paper. Once the amount of detail in the drawing is satisfactory, the investigator can trace the pencil markings with a thick, black marker.

Thus the scene outline and evidence will be black on a large white area of paper, and each of the vehicles will be drawn in a specific color on clear plastic sheets. The scene and vehicle diagrams are now ready for recording.

VIDEOTAPE RECORDING EQUIPMENT

In videotape recording, the audio and visual information is encoded onto magnetic tape. Broadcast-quality recording normally utilizes tape 1 or 2 in. wide on which separate tracks are provided for video, audio, and frame identification information. The equipment used in conjunction with this tape includes high-resolution cameras, broadcast-standard videotape recorders, and computer-aided editing machines.

Recent advances in technology have provided relatively inexpensive videotape recording equipment designed for amateur use. Generally cameras and recorders in such systems use ½-in. videotape. The narrower tape format provides for considsiderably less sophistication than is found in professional equipment; however, reasonably good quality can be achieved with these less expensive systems.

Typically, animation effects are produced by using the video camera in a stop-start mode. A subject is recorded for a short period of time. Then it is moved slightly and an additional recording is made. The simple process of stringing together individual sequences of material is referred to as "assemble editing." This method of recording usually produces interference in the picture during playback because there is no synchronization of the individual frames from the completion of one sequence to the beginning of the next. Such interference can be quite distracting to the viewer.

A technique referred to as "insert editing" minimizes these effects. To accomplish this, it is necessary to produce a control track on the videotape to encode the video information during the actual recording session. The control track consists of a string of electronic pulses, usually located on one of the tape's audio tracks. These pulses identify each frame of the tape so that the video and audio material can be played back properly.

The control track is readily produced by videotaping a black, nonshiny surface throughout the portion of tape that will be used for the reconstruction segment. Individual segments are now recorded onto the preprocessed tape by using the video-dub feature of the videotape recorder. The dubbing process uses the line of control pulses on the tape to synchronize the individual frames in the recording, which results in a more stable picture.

The investigator may be able to use the raw videotape produced by insert editing as described earlier. If still better quality is desired for the finished product, additional editing of the tape will be required. Such editing may involve the use of a controller unit governing the operation of two videotape recorders. At a minimum, editing may be performed between two separate videotape recorders. In the latter case it will not be possible to perform the editing at an exact frame and so some interference will still be present in the final picture. For a more complete discussion of editing techniques, the reader is referred to texts on this subject (*5,6*).

The quality of the final recording will depend to a great extent on the sophistication of the equipment used and on the skill of the operator. The results that can be obtained using inexpensive recording equipment are quite reasonable. Furthermore, the recordings produced are vastly superior to static diagrams in their ability to display complex collision situations.

ANIMATION AND RECONSTRUCTION TECHNIQUE

Historically animation has primarily been associated with film making. Numerous techniques are used in film animation (*7*). The basis for all of these is that a motion picture camera is used to make single-frame exposures of a subject, which is moved slightly between frames. The camera and the background remain static, and when the film is projected at normal speed, persistence of vision provides the illusion of fluid motion of the subject. This basic technique has been adapted for use with a video camera and videocassette recorder to provide a visual display of vehicle movements in a collision situation.

The basic methodology is to overlay scale diagrams of the vehicles on a scene diagram drawn to the same scale. The vehicle diagrams are essentially transparent so that physical evidence on the scene, and even on the vehicles themselves, can be observed. This enables the viewer to identify locations at which portions of physical evidence match up. These can be the location of a vehicle's wheel on a tire mark in the roadway or the conjunction of points of mutual contact between two colliding vehicles. The scene generally is left stationary and the vehicle diagrams are moved in stages to produce the animation.

Before the recording process begins, the movements of the vehicles must be established for each recorded segment. It may be necessary to calculate detailed position-time histories of the vehicles over the entire collision sequence in order to be able to produce animated vehicle motion in real time or in precise slow motion. Such data may be required if a knowledge of the relative locations of vehicles or objects, or both, is of primary interest in the reconstruction. This information may well be desired if the main question to be considered is one of driver's perception time, the location of a pedestrian with respect to the striking vehicle at some point before the impact, or some similar issue.

In cases where there are no time-specific issues, trial-and-error positioning of the vehicle diagrams on the collision scene may be used to reconstruct the sequence of vehicle motion. In such instances it may only be necessary to illustrate how the physical evidence with respect to vehicle damage and marks at the collision scene is to be interpreted.

Specific positions for the vehicle diagrams should be marked on the collision scene for each segment being recorded. It is convenient to draw small pencil lines on the collision scene at the desired intervals. The investigator will advance his vehicle diagram from one interval to the next along this line of movement intervals. The front edge of the plastic sheet containing the vehicle diagram might be used as the reference line that is placed at each pencil mark.

For a two-vehicle collision, the investigator might begin videotaping the collision sequence at some point before the first impact. The vehicle diagrams will be moved toward each other at a rate based on an estimate of their velocities. If one vehicle is traveling faster than the other, it will have to be positioned farther away from the point of impact (POI) than the other if they are both to meet at the designated POI.

It should be noted that as a vehicle makes contact at the POI, its speed will be reduced rapidly and the distance between the penciled movement intervals will become shorter as the vehicle decelerates. Also, this vehicle will likely begin to rotate and establish a new line of travel based on the forces acting on it. Thus a rotation rate will have to be marked through some curvilinear set of penciled intervals. If the case vehicle is to be involved in a secondary impact with a third vehicle, the rotation rate will be governed by the interval rate that will bring the vehicle to the POI at the required time.

The desirability of large-scale diagrams now becomes apparent. On such a large scale, small reference marks penciled in to identify specific vehicle positions are not visible on the videotape. In addition, when the vehicle diagrams are moved, it is difficult to keep them oriented in a straight line from one interval to the next. Slight deviations from the path of travel can be very noticeable when small-scale vehicle diagrams are used. With large-scale diagrams these slight orientation errors become indistinguishable and the vehicle movement appears more fluid.

When the vehicles strike each other at the POI, some crushing should be shown in the vehicle diagrams. This crushing can be imitated by substituting vehicle shapes with progressively greater crushing until the final one shown is the crushed shape that resulted from that particular impact. (This substitution technique is shown in Figure 2.) Usually the intermediate crush shapes are estimates of how the vehicle would be expected to crush in the real collision; however, the amount of crush should be accurate in positions where physical evidence is to be matched.

Before recording, the investigator should choose a large enough work site. He will need to move around the scene diagram and will need room for the camera and lighting. If possible, the camera should be mounted on top of the collision scene, pointing straight down. In a film studio this is not a problem because there is usually a ceiling grid for the attachment of lighting sources. In a regular office environment it may be possible to mount the camera on a large tripod and still shoot straight down at a collision scene that passes between the outstretched legs of the tripod. If the collision scene is too wide to be accommodated by this arrangement, the tripod may be placed on a large work table.

Direct overhead lighting of the scene should be avoided because the transparent sheets containing the vehicle diagrams reflect light into the camera mounted above the scene. The intent is to produce an environment with little shadow and an even exposure around the entire surface being recorded. At a minimum, two floodlights placed on opposite sides of the video camera can provide a reasonable amount of balanced lighting.

One difficulty with the use of a large scale is that for collision events taking place over a considerable length of roadway it will probably not be possible to place the entire collision scene in the view of the camera. Moving the camera to various locations along the scene diagram is awkward at best. Instead, the collision scene should be moved underneath the stationary camera, giving the illusion that the camera is being moved. The scene diagram should be moved at regular intervals. This can be accomplished by establishing a reference point on the floor next to the edge of the scene diagram. The scene diagram can be scrolled for an established distance interval for each recorded segment relative to the reference line.

CASE STUDY

The animation technique will be illustrated by means of a case study of a real-world collision that was investigated and reconstructed by the authors. It should be noted that this particular reconstruction is based solely on matching physical evidence observed from the damage to the striking vehicles and that identified at the collision scene. The intent in producing a videotape of this particular collision was to show how the pieces of physical evidence fit together to support the reconstructed vehicle movements in a complex series of events. Furthermore, the reconstruction is not meant to reproduce the collision events absolutely with respect to time (real or slow motion), but rather to show the contact between physical evidence of damage and that at the scene in the correct sequence. The accuracy of the vehicle movements between the contacts is not important in this case.

Figures 1 through 8 show vehicle movements during an example recording session. The example involves an offset head-on collision between two passenger cars, a 1978 Dodge Aspen and a 1978 Buick LeSabre. The Aspen entered a median-divided, limited-access highway, traveling the wrong way in thick fog. The two lanes shown are designated for travel in the same direction; the lanes for travel in the opposite direction are not shown in this study. The LeSabre rotated counterclockwise from this initial impact and was struck by a tractor-trailer.

A detailed inspection of the collision scene and vehicles allowed for the documentation of a large number of individual pieces of physical evidence that enabled specific vehicle positions and contacts between the involved vehicles to be identified.

Figure 1 shows the two passenger cars traveling toward each other just before the impact. The front portion of a tractor-trailer may be seen in the lower right-hand corner. The general area of the first impact between the passenger cars contained a

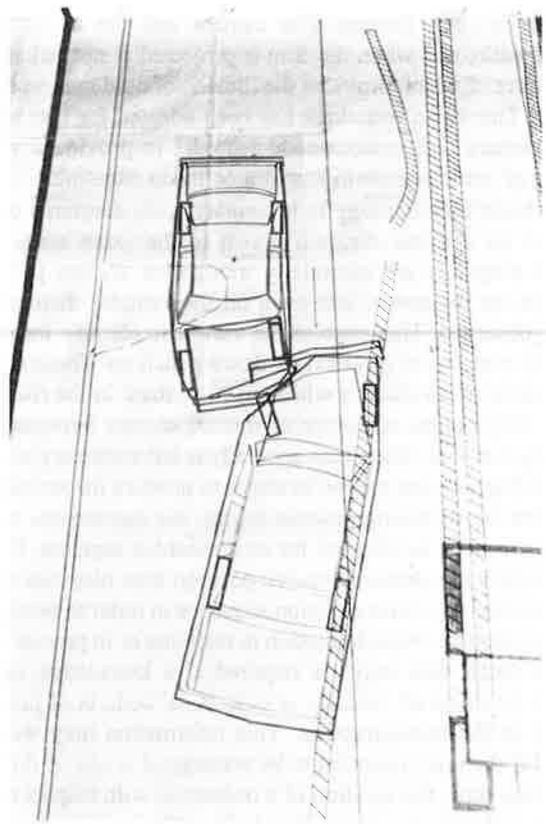

FIGURE 2 Frontal impact between Aspen and LeSabre.

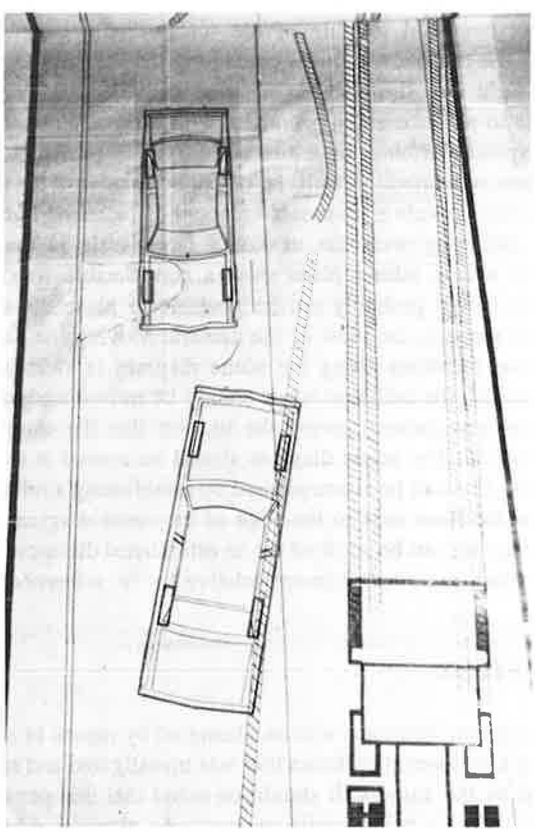

FIGURE 1 Preimpact vehicle locations.

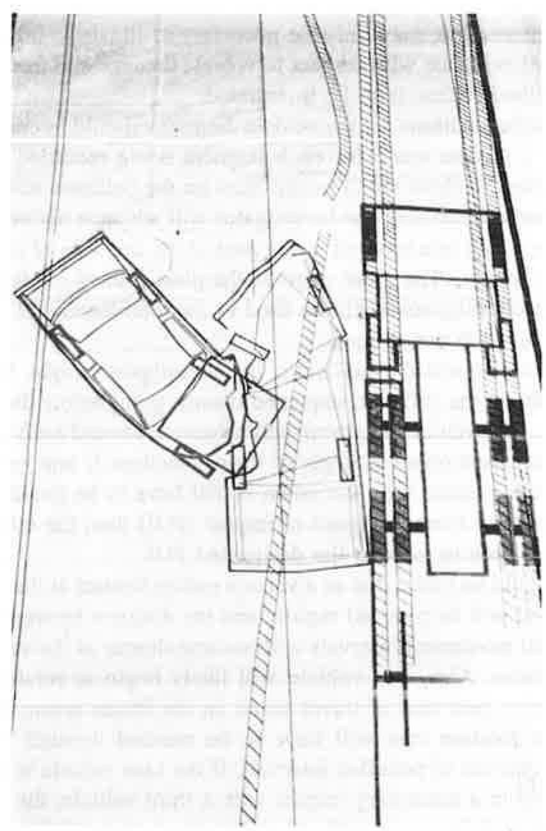

FIGURE 3 Conversion to sideswipe-type impact.

tire skid mark (long hatched lines) and gouges. A deep gouge in the center of the passing lane of the roadway could be traced to the driveshaft of the Aspen, which was found fractured during the vehicle inspection. In this way the physical evidence at the scene pointed to a specific location for the initial point of impact.

The damage to the front ends of both vehicles was also closely scrutinized to establish the overlap between the vehicles as they first made contact. The right edge of the direct damage could be easily identified on the front end of the LeSabre. Also, the LeSabre's front bumper was gouged deeply at its left corner. The location of the gouges along the bumper and their relative positions were measured accurately. Scale diagrams, which were drawn of both vehicles, allowed the gouges on the LeSabre's front bumper to be matched exactly with the end of a suspension bar on the front undercarriage of the Aspen. This suspension bar contained ridges in a pattern that exactly matched the set of gouges observed on the LeSabre's front bumper.

Not only was it possible to match the front ends of the two passenger cars at the initial contact, but also when the vehicles were placed on the collision scene, the fractured portion of the Aspen's driveshaft matched the location of the deep gouge mentioned previously. In addition, the LeSabre's right front tire was located exactly on the skid mark that was also identified previously. Thus the vehicle damage evidence and the scene evidence complemented each other (Figure 2).

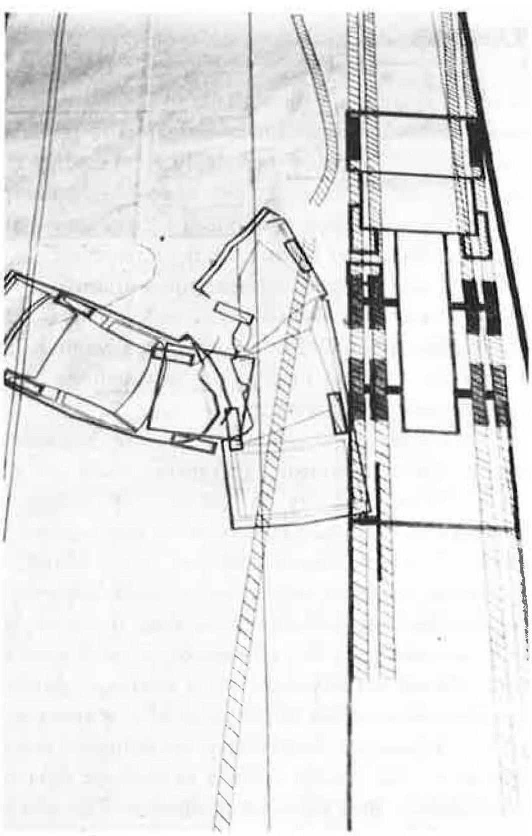

FIGURE 4 Brushing contact of right side of LeSabre against truck-tractor's wheels and an impact of the trailer's landing gear with right rear end of car.

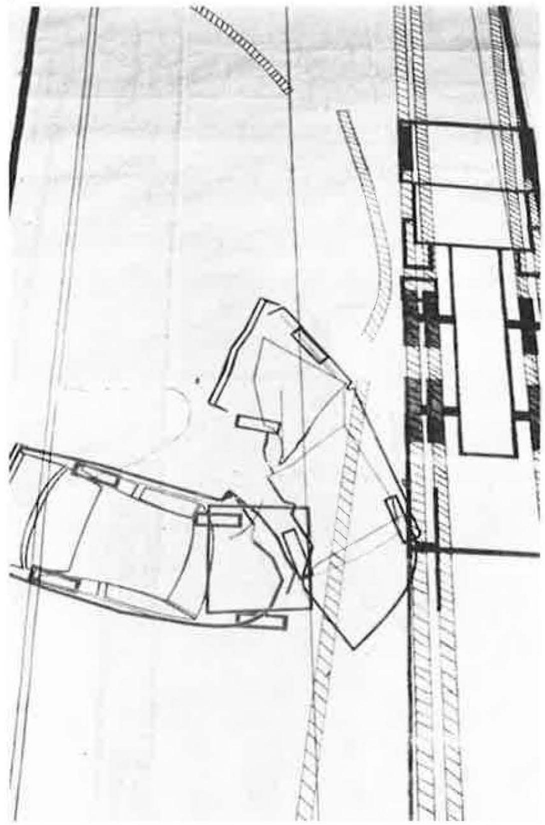

FIGURE 5 Crush to the right rear end of LeSabre.

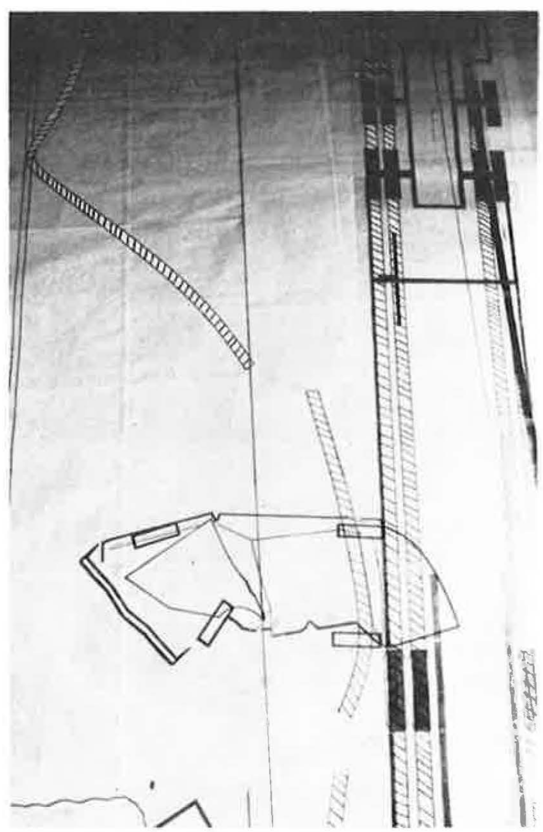

FIGURE 6 Impact to left rear fender of LeSabre by rear wheels of trailer.

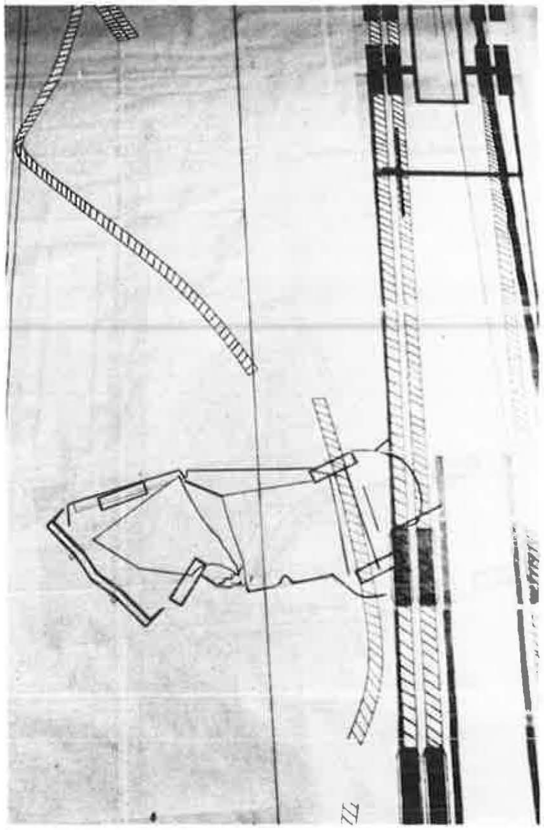

FIGURE 7 Crush to left rear fender of LeSabre.

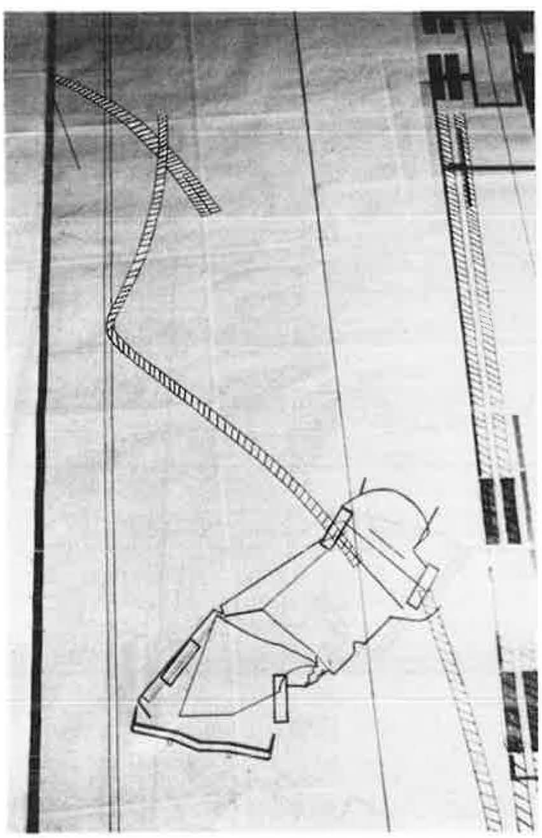

FIGURE 8 LeSabre rotates strongly counterclockwise toward final position.

The rest of the physical evidence that led to the detailed reconstruction of this collision will not be described at length. All other vehicle movements were based on interpretations of physical evidence similar to that just described for the initial impact.

After the initial frontal impact, the Aspen rotated counterclockwise and contacted the left side of the LeSabre (Figure 3) and the LeSabre rotated counterclockwise toward an adjacent lane containing the approaching tractor-trailer. The LeSabre sustained a brushing contact to its right side from the wheels of the truck-tractor, followed by a substantial impact to the right rear end by the trailer's left-side landing gear (Figures 4 and 5).

The LeSabre continued to rotate so that its rear end slid underneath the trailer, and the left rear wheels of the trailer struck the rear left side of the car (Figures 6 and 7). (Note that at this impact the collision scene had to be scrolled to keep the vehicles in view of the camera.)

After this last impact, both vehicles followed paths along scene evidence to their final positions. The tractor-trailer's wheels were locked from braking and produced a set of skid marks at the collision scene, which allowed the determination of its final position. The LeSabre rotated strongly after the third impact, and this produced a set of curved tire scuff marks and fluid sprays on the scene, which allowed the car's precise location to be determined on its way to its final position (Figure 8).

CONCLUSIONS

With the technological advances made in videotape recording equipment it is now possible for investigators to produce animations of collision events of reasonably good quality at moderate cost. However, although the capital cost of the equipment is not great, there is a hidden cost in terms of the time that must be spent in recording and editing the reconstruction.

The benefits of this type of videotaped animation can be substantial. Such graphical displays provide a useful medium for describing the importance of evidence from vehicle damage and the collision scene as these relate to situations involving quite complex vehicle dynamics.

The use of computer programs for collision reconstruction has become quite common. Programs such as SMAC (*8*, pp. 155–173) rely heavily on matching the output of the collision algorithm to the physical evidence documented by the investigator. Reconstructing a collision using SMAC is an iterative process; the input conditions are modified in the light of the accumulated results from various runs. Because physical evidence is an exact indicator of position, a videotaped reconstruction produced entirely from such evidence should give valuable information to the investigator who is about to input data into such a program. Conversely, the output of computer-based reconstructions can be utilized as the base data for the vehicle movements in a collision animation. The videotaped reconstruction brings the computer output to life in a much more meaningful way than a static plot of the vehicle dynamics. Computer-generated graphics have been used directly for videotaped reconstructions of collision situations (*9*, *10*). An extension of the two-dimensional method reported in this paper has been the recording of reconstructed collision events with the use of three-dimensional models (*11*).

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Analysis of High-Hazard Locations: Is an Expert Systems Approach Feasible?

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The focus of this paper is the detailed analysis of specific highway locations that have been identified as hazardous in the framework of a state Highway Safety Improvement Program (HSIP). A methodology is proposed for implementing a microcomputer-based prototype expert system that would perform the location analyses described here. A prototype system would be used to assess the feasibility of building usable microcomputer-based expert systems for this application and to make recommendations for the design and implementation of such systems. By automating these activities with low-cost, easy-to-use-computer technology, it is hoped that the effectiveness of state highway transportation agency operations will be enhanced and that the provision of consistent and comprehensive analysis procedures will improve the overall safety and efficiency of the highway network. For automation to be feasible, certain minimum requirements must be met. With those in mind, a review of current state HSIPs was conducted. It was concluded that computerization of these analyses by using expert systems concepts on a microcomputer is technically feasible. A methodology to develop such a system for a state highway agency is proposed.

Last year 43,607 people died in traffic accidents on the nation's highways (*1*). Traffic accidents are one of the major causes of death in the United States today and have been since the beginning of this century. However, it was not until the late 1950s and beyond that the numbers began to grow to alarming proportions. The combined effects of the growing highway

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