Handling Accident Investigations & Reconstruction

By Dennis Andrews, Ph.D.

Professional investigators and reconstructionists in the transportation industry are necessary for several reasons. Law enforcement investigates accidents for the possibility of criminal charges, while insurance companies and lawyers use investigators for liability issues during civil trials or for use in establishing tables for premium rates. Each year, the National Automotive Sampling System-General Estimates System (NASS-GES) and the Fatality Analysis Reporting System (FARS) randomly collect about 57,000 police accident reports (PARs) and data from states' existing documents (e.g., driver licenses, hospital medical records, coroners reports, vital statistics) to evaluate and publish a statistical analysis information report on motor vehicle collisions (National Highway Traffic Administration [NHTSA], 2002). In the last few years, NHTSA has decided to use the terms "impacts, crashes or collisions." It felt that the term "accident" implied that collisions could not have been avoided. Most people outside of NHTSA still use the terms "accident investigation" or "accident reconstruction."

The GES report lists various statistics that are useful in a general way. The statistics do not indicate the Delta V severity of collisions or present crush deformation data for comparison and profiling. The main purpose of this report is to provide researchers and interested parties with a large database of collisions statistics for safety, design and cost analysis.

Trucking companies investigate accidents involving their drivers so that they can determine whether a specific accident was preventable. If preventable, the driver is advised and a note is placed in his file for future performance evaluations. It should be noted that the term preventable used by the trucking industry does not mean the driver was liable or caused the collision. This term has meaning only in the trucking industry and consensus agrees it is used to determine whether the driver did everything reasonably possible to avoid the impact, even if he was not the cause.

Obviously, the legal profession and insurance companies rely heavily on quality investigations and reconstructions for a purely monetary motivation. Plaintiff attorneys rely on investigations for part of their income, and the insurance industry relies on investigations as part of a rejection of a claim. Insurance companies also use the results of investigations and reconstructions to estimate premium costs in a given area for the type of vehicle, age of the driver, use of the vehicle, etc.

Motor vehicle manufacturers use collisions statistics to design safer vehicles for the occupants and to help reduce collision repair costs. Motor vehicle manufacturers perform their own crash testing using sophisticated anthropomorphic dummies to determine the severity of several types of impacts and to correlate these data with the probability of injury. Governments worldwide regulate the manufacture of products, including motor vehicles for the safety of the public. These regulations can vary from country to country, and they are usually based on the personal opinions and research of the regulators and manufacturing officials.

Accident investigations and reconstructions are not confined to motor vehicle accidents—they include all types of possible injuries. National Safety Council (NSC) and OSHA are leaders in the fight against on-the-job injuries. These organizations offer counseling and seminars to help employers reduce injuries and deaths. Product liability is another area where a quality accident investigation is necessary to learn the mechanism of injuries and ways to design out problems.

Qualifications for the accident investigator/reconstructionist vary widely. They can include a degree in an area related to the investigation, or education through seminars, individual courses or experience. If the investigator or reconstructionist is an independent consultant rather than an employee, s/he may include testifying as an expert as part of his/her consulting service.

Federal court rules of evidence provide clearly for the necessary qualifications to testify as an expert witness on a subject. The rules state that "a person may qualify to give expert opinion based on their skill, knowledge, experience, training or education." In fact, a degree is not necessary unless the expert opinion is of a nature where a licensed professional would be necessary. In the case of a motor vehicle accident investigation/reconstruction, many people without engineering degrees qualify as experts. Accident investigation/reconstruction is currently not taught in engineering schools.

Most engineers believe that their training, whether it is civil or mechanical, constitutes sufficient education or training for accident investigation/reconstruction. While engineers as well as others are taught physics, specifics of accident investigation/reconstruction are not taught. Specific subjects required for a quality accident investigation/reconstruction include crush deformation, restitution and stiffness of specific vehicles, tire marks, including deceleration marks, and roadway evidence. Several colleges, universities and organizations offer accident investigation/-reconstruction training through individual courses or specific seminars.

Equipment for Scene Investigation/Reconstruction

Equipment varies widely, but most investigators/reconstructionists use the same basic tools. Tools are used to measure, categorize or preserve the forensic evidence gathered at the scene of an investigation. Forensic evidence that must be located, preserved and measured includes the final resting positions of all vehicles, pedestrians and bicycles; vehicle debris and its pattern; tire marks (including deceleration and yaw marks); the type of roadway and its coefficient of friction; the condition and type of shoulders, shoulder ruts or drop-offs; permanent damage of all vehicles and any missing components; and roadway gouge or scrape marks as well as off-roadway damage or marks.

Tools can include a 25-ft tape measure, a 100-ft tape measure, inclinometer, chalk and carpenter's crayon, weatherproof cards and waterproof pens, flashlights, a long-distance measuring device such as a laser light and a good-quality 35mm camera with 400 or faster speed film. Also needed are preprinted forms for use when describing roadway evidence or measuring the

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crush deformation of vehicles (Baker, 1986). More sophisticated tools such as computer programs and animations can be used in analyzing evidence gathered. Some of these programs are expensive, while the more simple programs are less expensive.

Additional tools that should be carried to remove specific parts required for further analysis are a set of screwdrivers, drive sockets, Allen wrenches, a cordless drill and a 1-sq-ft tile or piece of wood for use in photos. This tile is used as a reference when taking photos to determine the dimensions of debris or other items within the photo. It should be said at this point that the removal or damage of evidence without proper authority could destroy your case. Tools both for use in the field and in the office can be very personal, and as the investigator/reconstructionist gains experience, additional tools and even special tools will be devised and needed.

Photographic equipment, whether a 35mm camera, a video camera or a digital camera, is a necessity for every investigation. The saying "a picture is worth a 1,000 words" is more than appropriate for investigative work. When using 35mm film, consider developing this film with a glossy finish rather than a matte finish. Glossy prints can be magnified to identify subtle marks, striations or surface transfers. When a matte finish is used, the grain of the photo will be magnified as you magnify a select area for review. Simply obtaining enlargements may not be a better choice than magnifying the typical 4 x 6 color print, since as the photo is enlarged, the grain becomes hazy and subtle evidence could be missed. When taking 35mm photos of the scene, it is best to use a 50mm lens since it is agreed within the profession that this lens closely replicates the human eye. In fact, a 53mm lens more closely replicates the eye, but this type of lens is difficult to locate.

The video camera is a useful tool when motion is required over still photography. Some computers can import videotape and display specific scenes when paused. The paused scene could then be printed.

While this technology is exciting, the printed scene is usually not as clear as a 35mm print. With the popularity of digital cameras and e-mails, most people have chosen to use this to preserve evidence. One caution with digital cameras is that the actual picture can be manipulated; if this is done, the photo would be inadmissible as evidence for a true representation of either a scene or a piece of evidence.

Of course, while working at a scene, safety is of critical. Orange reflective vests should be mandatory for anyone working on or near the roadway. Other safety equipment includes a yellow flasher on the top of your vehicle if it needs to be parked on the roadway shoulder for any length of time.

A technical library is probably one of the most important tools, besides the Internet, that an investigator/reconstructionist can have. While it would be impossible, if not impractical, to have all available written documents of specific subjects, it is possible to compile a satisfactory library of documents for reference. The Internet is a valuable tool for research into subjects to which you do not have immediate access.

While at the scene, information to prepare a scale diagram must be obtained. Two types of methods, triangulation and coordination, are used. Triangulation simply indicates the measurement of three locations in reference to themselves. Coordination uses a reference line, which can be a curb line and a reference point and usually is the evidence itself.

There are many ways of documenting these measurements, including photography and video. There are more expensive methods that cost $10,000 or more. Given a sufficient amount of time, the standard tape measure or rolling measuring stick would be sufficient and accurate if these devices had been tested for accuracy by the local state weights and measures department. The best and simplest procedure to plot a curve would be to use the chord and middle ordinate method learned in geometry. Other methods are available, but the chord and middle ordinate method is universally used.

If the intersection is controlled by a traffic light, it is wise to obtain the operational schematic on the subject traffic light for review. The traffic light has various timing sequences, which can be very important in an investigation. Some traffic lights are more complicated depending on the number of roadway legs entering into the intersection. There are several signal indications for a typical intersection such as red, green and yellow, which may be accompanied by a yellow, red or green arrow (International Municipal Signal Association [IMSA], 1997). Many actions can be programmed into the central system of traffic signals, some of which consider speed, traffic flow and intersection design (IMSA, 1997).

Additional considerations of the accident scene, such as signs and markings of the roadway, should be investigated as well. Traffic control signs and markings are used to promote an orderly and predictable flow of traffic and to assist the driver in reaching his/her destination as quickly and as safely is possible (IMSA, 1993). At times, signs and markings are improperly placed by human error, or the traffic study is flawed and the sign or marking creates an unsafe hazard.

Another area which has a high potential of accidents that probably surpasses intersections is a work zone. Because of the appearance of mass confusion and work personnel moving in every direction, the driver becomes frustrated and may not perform the appropriate driving task. Work zones have specific rules and terminology such as shall, should and may. The word "shall" indicates a mandatory action, "should" an advisory action and "may" a permissive action. These terms are very important in reviewing a work zone accident to determine the appropriate seriousness of actions and placements of work zone safety equipment (IMSA, 1998).

Work zone safety is of such critical importance that many states have doubled or tripled the fines for violations in work zone areas. During an investigation involving work zones, a blueprint should be obtained since all work zones are planned well in advance of the start of construction. To further complicate the investigation, workers in work zones are usually from several different independent contractors within the state or municipality.

Evidence from Vehicles

Evidence such as damage, principal direction of force, hair and blood speaks volumes on how the accident occurred. Usually, the vehicle will have been moved to a salvage yard, and the inspection of the vehicle will begin there. Before inspecting the vehicle, all appropriate approvals must be obtained as well as special approval if any parts will be removed from the vehicle for analysis.

Weather is crucial if subtle evidence such as dust marks, blood and hair or skin transfers are to be maintained. Cover the subject vehicle if it will be stored outside until the inspection can be performed. The vehicle inspection is a good example of documenting evidence through a still camera and video camera. When making a video, there should be no sound on the tape—the video should strictly document the evidence without any description or narration.

Still photographs should be taken of all four sides of the vehicle as well as the top and underside. This way, all damage can be illustrated when you perform the inspection. Depending on how many times the vehicle was moved, damage from the collision must be isolated from any damage caused by towing the vehicle. It is equally important to document undamaged areas of the vehicle as well as the damaged areas.

Photographs, if done properly, can be used to determine the depth of crushed material. This process is known as photogrammetry. Although the process is widely accepted, it is not widely known how to perform the calculations. Photogrammetry can be simple or complex depending on the information needed from the photograph. The still camera must have a fixed focus rectilinear lens to photograph the side of the vehicle, and it must be at right angles to the side when determining crushed depth from the front of a vehicle. The lens should be level and at the height of the center of the mass of the vehicle pointing toward the center of the vehicle (Daley, 1986). The process is a simple mathematical scaling ratio calculation that multiplies a known unit of measurement in the photograph with a known unit of measurement of the subject part multiplied by the ratio to obtain the life size dimension.

The photogrammetry method can be used to determine the depth of crushed damage to vehicles or the size of roadway evidence in a photograph. It is crucial to have the life size measurements of several objects in the photograph to determine roadway evidence dimensions.

Photos that document the principal direction of force for each vehicle is crucial to understanding the before and after paths of the vehicles. It is also important to assist in determining the kinematics of the vehicle occupants and eventually the biomechanics and mechanism of injury. Film is inexpensive, and it should be used extensively for documenting any type of evidence. It is much easier to review a photograph than to visit the scene or the vehicle several times, if they are still in the condition they were in when you first inspected them.

If you are able to record video or take still photographs while your complete inspection is performed, this enhances your credibility and documents your methodology. Besides, large-crush subtle evidence such as striations and paint transfers should be included in your pictorial documentation.

Documenting evidence of seatbelt use is crucial when analyzing and investigating an accident involving specific types of injuries. All planes (sides) of the vehicle should be photographed at an acute and linear position to the plane. Overhead photographic documentation can be done by mounting the photograph on a PVC pole with a mechanism to snap the shutter. This overhead method of photography can be crucial if you need to determine the speed of a vehicle at impact from damage (crush information).

Anytime vehicle damage is the major method in analyzing the collision, the properties of metal parts must be considered. The stiffness of metals related to motor vehicle collisions is an indication of the resistance of a metal at a given angle to permanent deformation or crush. Restitution of a metal is the rebound relating to the angle and force of impact. Both of these values are necessary if an accurate an unbiased investigation and reconstruction are to be performed. Any results, conclusions or opinions without considering stiffness and restitution would be highly suspect at best, especially in low-speed collisions.

The undercarriage of vehicles can tell the angle of departure from the initial impact if undercarriage damage is compared to roadway surface gouges or scratches. Paint transfers can be very subtle or very obvious depending on the angle and speed at collision. Paint transfers occur when two surfaces with different color paint are forced together, and friction creates heat to temporarily melt the paint causing transfer.

Some investigators and reconstructionists claim that the thinning of sheet metal due to rust decreases the energy absorption of the metal and, consequently, more damage occurs at the same speed than with a vehicle with no rust. While this may sound logical—and it is—the less absorption from rust is negligible and at this time cannot be quantified. Most investigators and reconstructionists will agree that a severely rusted vehicle will incur a greater amount of damage at the same speed then a vehicle with no rust damage.

Another important area related to vehicle damage includes the matching of roadway scrapes, gouges and scratches with the undercarriage of the vehicle. This is especially important when one or more vehicle rolled over either before or as a result of the impact. There is also specific damage to vehicles other than contact between the vehicles themselves. Vehicles can leave the roadway and strike roadway signs, traffic signal posts, wooden poles, trees or culverts, and each of these impacts usually leaves a distinctive damage profile, which aids in identifying the dynamics of the vehicles.

The type of damage concerned with absorbing energy and speed determination comes from contact damage as opposed to induced damage. Contact damage is the damage directly caused from contact between two objects, and induced damage is a result of contact damage, i.e. breaking of the bottom of the windshield from the hood displaced rearward.

Wheel rims and tires can reveal important clues as to how the accident occurred. Tires can blowout slowly or quickly depending on the object they strike. Wheel rims can be bent from impacts with curbs, potholes or other objects. When tires and wheels are damaged, a thorough investigation should reveal the cause and also the effect on the vehicle itself.

For example, if a vehicle leaves the roadway and the driver attempts to return to the roadway, the inside edge of the tire will usually have scrape marks if the drop-off of the pavement is approximately four inches or greater. Fluid leaks on the roadway can tell a story of initial impact and after-impact travel as well as point of rest. Fluid naturally seeks the lowest point and will usually collect in the lowest point of the roadway. This should not be considered a point of rest.

Vehicle lighting can be crucial when investigating left or right turning vehicles and nighttime accidents. Headlights or turn signals that have one or two fila-

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ments can be used to determine what is called "cold shock" or "hot shock." If a lamp is illuminated, the filaments can reach temperatures as high as 2300 ºF. In this condition, if a severe force were applied, the laws of physics would dictate that the filaments would move or bend in the direction of this force. If the glass bulb breaks, the filaments will show signs of oxidation when it comes in contact with air Limpert, 1989).

When inspecting a vehicle, the lights must not be turned on since doing so before inspection and documentation will destroy this type of evidence. If you decide to move the lamps, special documentation and orientation up or down must be maintained. It is possible that if the glass is broken when the filament is hot, glass pieces will melt and adhere to the filaments wires. It should be noted that not all lamps and bulbs have the types of filaments the can be analyzed in this manner.

Vehicle interiors must also be inspected. Usually, evidence of the interior of vehicles consists of occupant movements and mechanisms of injury. Occupants always travel toward the impact or forward. If the impact is offset by 30 degrees from the centerline of the vehicle, the occupants will move toward this 30-degree impact. Windshields can become cracked from various objects such as from unbelted individuals, or in days past, from occupants who only used a lap belt, which allowed the upper torso to rotate forward. Windshields are now made so that they do not break into many pieces and seriously injure the occupant. They are designed to shatter and stay in one piece. Side windows are not designed the same way. Shattered glass from side windows can indicate whether the force came from inside or outside the vehicle.

Instrument panels or dashboards used to be very dangerous and produced significant injuries at lower speeds than today's designs. Today's dashboards and steering wheels are padded, and airbags have been designed to prevent the occupant from reaching these structures.

The force is a result of the acceleration or speed of an object and its mass. This force increases or decreases depending on the time the occupants come to a stop. Contact between vehicles usually occurs over a time period of 100 ms, which is the equivalent to 1/10 of 1 second. Airbags usually deploy in 20 to 30 ms, which is necessary to stop the forward movement of occupants. Seatbelts can be analyzed for use or nonuse by the occupant. The seatbelts that have been used usually will show marks on the latching system, stretching or loading of the belt fabric (Rivers, 2001). Injuries compatible with extreme forward displacement are usually caused by the nonuse of seatbelts.

Lower surfaces, such as underneath the dashboards, are another source of serious injury for the unbelted individual. The typical injuries include fractures of the tibia, fibula, femur or hip. An investigation of the area is needed to match the injuries to the occupant. This type of investigation is most useful when none of the occupants admit driving, and when alcohol or drugs may have been involved. Hair, blood, skin tissues and injury patterns tell a story as to the seated position of occupants. The inspection should determine distances to the dashboard and steering wheel from the suspected seating position. This information is necessary in assessing seatbelts use.

With the onset of airbags, injuries have been further reduced. Deployment of airbags can give an indication of the Delta V or the severity of impact. Airbags can deploy at various Delta V speeds usually more than 14 mph (Marsh, 1993). In impacts between 8 and 14 mph, the airbags may deploy. The direction of impact for proper deployment of the airbags is usually within a range of 30 degrees of either side of the vehicle's centerline.

Seat cushions, seatbacks and headrests are very important when inspecting a vehicle. A properly positioned headrest can drastically reduce injuries from whiplash. Whiplash occurs when a rear-end impact forces the torso of the occupant forward when the head and neck, still wanting to occupy the same space (inertia), remains stationary.

The seatback also plays an important part in energy absorption as the torso is forced into the seatback and the stored energy is released, thus propelling the torso of the occupant forward. This force can at times be faster than the vehicle itself since it employs a slingshot effect.

In side impacts, it is also important to inspect the glass fragments of the side windows as well as match up occupant injuries to the side door and the center console. Vehicle structures supporting the roof are usually identified as A, B and C posts beginning at the corners of the windshields and moving rearward towards the rear window.

Useful information can be obtained from bumpers and their accompanying structure. Bumpers have thresholds where once surpassed, permanent damage will occur. All bumper systems are not equal and have different damage thresholds. Damage thresholds are much lower for barrier crash tests than in real-world, vehicle-to-vehicle impacts. This is because in barrier impacts, all energy is used to damage the crash-test vehicle and not the barrier, while in real-world impacts, both vehicles absorb energy from the impact.

The structures of bumpers include bumper bars, bumper isolators, frame brackets and Styrofoam absorbers. Bumper isolators are small shock absorbers mounted horizontally behind the bumper; they are intended to absorb the energy from impacts before reaching the frame of the vehicle. By analyzing the distance of movement or collapse of the isolator, one can compare with tests to determine an approximate value of energy absorbed. With this information, an approximate impact speed can be determined. Of course, this procedure must be done for both vehicles for if only one vehicle is inspected, only half of the evidence has been analyzed. Styrofoam bumpers are made to be used once since these types of bumpers terminally deform when absorbing energy, whereas the isolator will usually return to its undamaged position if the impact has not surpassed the isolator's threshold.

Occupant Protection & Movements

The protection of occupants has been of great concern for many years in the automotive manufacturing industry. Lap seatbelts were originally available in the early 1960s, and since then, manufacturers have developed lap and shoulder belts, front and side airbags, crumple zones and energy-absorbing interior components.

Occupants are not injured from speed; they are injured by stopping quickly, as when impacting a solid object. Seatbelts must be used in order to allow the occupant to "ride down" the impact. This term describes the lengthening of time the occupant decelerates. Without this ride-down time, the occupant would sustain much more severe injuries at the same speeds.

Seatbelt examination is crucial in any kinematics or biomechanical analysis of occupant injuries. Seatbelts are designed to stretch from the loading by the occupant, and signs of stretching become apparent. Stress marks can also be seen at the buckle and the retractor. The investigator should take special note when examining seat belt use to pull the retractor and examine the interior mechanical parts.

In loading the seatbelts, the mechanical parts of the retractor will usually exhibit evidence of applied force. Also, seatbelt buckles and latches will exhibit stress marks on the webbing. Few cars have lap belts only; if they do, they are usually in the center rear seat. If a severe impact occurs, severe abdominal and interior organ injuries can occur from these forces.

Child seats are another concern when inspecting the vehicle's interior. Child safety seats are usually installed using the seatbelts of the vehicle. Later-model vehicles have a system called a latch system. This system does not use the vehicle's seatbelts to install the child seat. Instead, the seat is installed using two attachments in the vehicle seat and the latch system belt supplied with the child safety seat.

During an inspection, an investigator may find the seatbelt webbing torn in half. This can occur when the emergency personnel extricate the occupant or when the collision force is so great that the seatbelts simply give out. Evidence of the latter is where the ends of the seatbelt do not demonstrate a clear and clean cut as opposed to frayed ends. The connection of the seatbelt to the body of the vehicle is also of importance and should be thoroughly inspected for signs of stress, straining or displacement.

Airbags are of primary importance for restricting forward movement of the occupant. The airbag deploys so quickly that when the occupant strikes it, the airbag starts to deflate. Airbags deploy at approximately 200 mph and can cause injuries such as abrasions, bloody noses and arm or wrist fractures, which can all help to determine the driver's position. For example, if a driver has both hands on top of the steering wheel when the airbag is deployed, the force of the airbag could move the hands and wrists violently into the upper windshield, cracking the windshield and breaking bones.

There are special occupant safety restraints for specific purposes. A specific restraint for pregnant women, which allows for the safety of the fetus, recommends that the lap portion be placed at the lowest possible position on the pelvic girdle. If there is bruising on any other parts of the body, then the seatbelt was worn improperly. Another type of child seat restraint is a car bed for medically fragile infants and seatbelt vests for children who constantly attempt to get out of their child seat (NHSTA, 2000).

Occupant movement is termed kinematics. Kinematics differs from biomechanics in that it studies motion exclusive of the influences of mass and force, while biomechanics is the science concerned with the action of forces on the living body (Williams & Wilkins, 1997). Newton's laws of physics applied to occupants state that occupants will move in the direction of the force. In other words, if the collision is to the right front corner of the vehicle, all the occupants will move in that direction.

When determining injury patterns and seating positions, a right front impact may allow the driver to slip out of the shoulder strap (over the left shoulder) and be restrained only by the lap belt. If the collision is severe enough, it may appear to the untrained investigator that only a lap belt was in use. Conversely, the right front passenger would be restrained by both the shoulder strap (over the right shoulder) and a lap belt.

Seatbelts are important when the vehicle spins or rolls over after the collision, since seatbelts are designed to hold the occupants in place. Movement of the occupants during a collision may force them to be out of position; if the airbag is deployed, it can strike the occupant and produce injuries. This is the main reason airbags have precise sensors related to the Delta V severity and principal direction of force of the impact.

A review of human anatomy and the medical records of all injured occupants will give a good indication of the seating positions and if seatbelts or airbags were in use. An occupant submarining under a lap belt that was too loose usually causes lower-extremity injuries such as fractures to the tibia, fibula and femur. Injuries to the upper extremities, such as the ulna, radius and humerus, usually indicate a side impact and airbag deployment in which the arms are on top of the steering wheel and out of position of secondary impact.

Upper-extremity injuries alone cannot be used to determine whether seatbelts were in use. Spinal injuries are usually signs of rear impacts. In a whiplash-like movement, the cervical spine is under stress by the difference in movement and velocity between the torso and the head/neck complex. The thoracic and lumbar spine can also be affected by the bounce or rebound of the seatback possessing stored energy from the compression of the torso.

When crash testing for injury determination and probability, human subjects cannot be used past a point of injury threshold. Anthropomorphic dummies, which are designed to be as humanlike as possible, are used. It is acknowledged in the scientific and biomechanical community that anthropomorphic dummies are an adequate substitute, but they still do not replicate the human body or movement. Given this difference, many investigators/reconstructionists are highly skeptical when others attempt to equate movement and forces of the anthropomorphic dummy to the human form. Cadavers are used in research, but the same problem exists as with anthropomorphic dummies.

Delta V Measurements

Determination of the severity of the collision is of primary importance in determining speed and probability of injury. One of the most widely used and misunderstood numerical ratings of injury severity is the Abbreviated Injury Scale (AIS). This system was developed by three organizations between 1969 and 1971—the American Medical Association, Society Automotive of Engineers and American Association for Automotive Medicine (Hyde, 1992). The theory and necessity for such a rating is understood, but the apparent simplistic approach does not compare with a high degree of accuracy.

Since its inception, AIS has changed several times. There are other groups and ratings, but to accurately determine the probability of injury from a specific collision and specific Delta V, the scales are of little value. The scales were designed to measure the threat to life. For example, two broken legs would not be considered a serious threat to life, as would a punctured stomach or intestine. Furthermore, the scale allows only for the most serious injury rather than a group of injuries that together could be greater than the most serious injury in terms of "threat to life."

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This is not to say that these data are worthless, but if one uses this to determine the probability of injury related to damage and severity of collisions, one must be cautious in reaching any scientific conclusion. Injury scaling is a complex process that is further complicated by the fact that all doctors do not agree with certain injuries representing a scale of threat to life. Delta V is only as good as the scientific analysis behind it. If the time difference of two impacts were compared to the exact impact speed for the same two impacts, the impact with the shortest time would have a higher probability of injury to its occupants.

Two-Wheel Vehicles & Pedestrians

Two-wheel vehicles consist of bicycles and motorcycles. Both must be thoroughly investigated since they are quite different in their use and dynamics. Motorcycles and bicycles are known as articulated vehicles such as semitractor-trailers. Motorcycles come in various sizes and shapes, which include semicustom or custom (choppers).

Motorcycles can be stopped by applying the rear brake, which is usually activated by a foot pedal, and the front brake, which is activated by a hand-pressure-activated brake on the handlebars. The novice motorcycle operator will usually only activate the rear brake in emergency action, but the experienced rider will activate both the front and rear brakes. The most efficient manner of braking with a motorcycle is by applying both brakes at the threshold of lockup. In other words, prior to either wheel locking. This maneuver takes some practice and is usually accomplished by experienced riders. The reason for modulating the front and rear brakes is to take advantage of available roadway friction.

If the front brake is applied by itself, the rear of the motorcycle, since it is articulated, may attempt to swing around to either side, much like the jackknifing of semitractor-trailers. On newer, more expensive motorcycles, one or both of the brakes are of the antilock braking system (ABS)-type. This means that the operator does not have to find the threshold of lockup but can simply jam the ABS brakes and the brake system will modulate the brake for the most efficient braking.

When investigating motorcycle accidents, tire marks or deceleration marks are important and must be interpreted correctly. If the motorcycle is modulating during braking, the braking efficiency could be slightly more than 100%, but if the rear brake only is used, the braking efficiency is approximately 40%. These percentages are divided 60% for the front wheel braking and 40% for the rear wheel braking. The 60% for the front wheel is due to the fact that during braking, weight shift transfers the weight to the front wheel, much like a passenger vehicle where the front end dips during braking (Baxter, 1993).

One must be cautious in identifying deceleration or skid marks from motorcycles since the rear braking mark will usually be long and wavy because the motorcycle will weave back and forth during deceleration. If the rear brake is locked while the front brake is modulating, the rear brake deceleration marks will be more or less be straight (Baxter, 1993).

If a motorcycle operator believes that

FIGURE 1 Speed Estimate from Crush

$$b1=\frac{\Delta V-b0}{C\ ave} \qquad bo=\frac{\Delta V-b1}{C\ ave} \qquad A=\frac{W\ bo\ b1}{g\ wd} \qquad B=\frac{W\ b1^2}{g\ wd}$$

$$G=\frac{A^2}{2\ B} \qquad E=[G\ wd+(A+B\ \bar{X})\ area]\ (1+\tan^2\theta)$$

$$E=\frac{wd}{3}\left[\frac{A}{2}(C1+C2+C3+C4)+\frac{B}{6}(C1^2+C2^2+C3^2+C4^2+C1C2+C2C3+C3C4)+3G(1+\tan^2\theta)\right]$$

$$S=\sqrt{\frac{E^*\ 30}{W}} \qquad \Delta V=\sqrt{\frac{2\ E^*}{m1\left(1+\frac{m1}{m2}\right)}} \qquad e=\frac{Vs}{Vc}$$

$$BES=\sqrt{\frac{2\ g\ E^*}{W}} \qquad \Delta V1=BES(1+ec)\sqrt{\left[\frac{k1+k2}{k2}\right]\left[\frac{m2}{m1+m2}\right]\left[\frac{1-eb^2}{1-ec^2}\right]}$$

e= coefficient of restitution; bounce; ec is from car to car test, eb is from barrier test; Vs=separation-rebound; Vc=closing-impact Vc and Vs for car to car or Barrier; k= stiffness of specific vehicle, A and B values

BES= barrier equivalent velocity,fps= impact speed into flat rigid barrier to cause same amount of crush damage profile as seen in the case vehicle being examined; *= Energy, ft lbs, both cars from crush

m2= mass of vehicle #2, lb-sec²/ft, W/g; m1= mass of vehicle #1, lb-sec²/ft, W/g

C1,C2,etc = crush measurements, inches

E = energy of displacement (crush) relative to spring constant, inch lbs, unless shown * per car

$\bar{X}$ =distance of centroid of damage from exterior surface of the vehicle

area= area of crush in sq inches, width x depth or width x ave. crush

$(1+\tan^2\theta)$= PDOF, direction of force if not perpendicular to the car, not to exceed 2 or 45 degrees

ΔV = Change in velocity over time, fps, crush dissipated from barrier tests for losric can be impact speed for non losric

b1= Slope of speed vs. crush (change of Delta V per inch of crush) inch sec/inch

bo = inch /sec max barrier velocity w/o permanent crush-Y intercept; assumed (not tested) the “no damage threshold” to be 5mph (88 inch/sec) with no rebound

A = constant stiffness coefficient lb/inch amount of resistance of the car surface to any damage

B = constant stiffness coefficient lb/inch² spring stiff. Resistance to further permanent crush once damage has begun and the force has overcome the stiffness value of A

G = constant stiffness coefficient lb energy dissipated w/o doing damage

g = gravity 32.2 fps² ; W=Weight lbs; wd= width of damage inches

C ave= average crush of test vehicle barrier impact inches s/he cannot stop in time, s/he will attempt to “lay down” the motorcycle in an effort to avoid impact with a hard object. Scrapes, gouges and scratch marks on the roadway should be matched with similar marks on the motorcycle. During the examination of the motorcycle, the rear tire, if braked, will show a patch on the tire, which is caused by the locked tire sliding along the roadway. If the front brake is modulated, you would expect to see what is described as “speckling.” Small stones that create white marks on the outer circumference of the tire can identify speckling. These white marks are caused by small stones on the roadway, which during modulated braking are caught between the roadway and the tire.

Another area to consider in motorcycle accidents or bicycles accidents is roadway edge drop-offs. Drop-offs exceeding approximately two inches create a serious hazard for both bicycles and motorcycles due to the small sidewall of the tires. This size of drop-offs will usually have little effect on a motor vehicle tire. If a motorcycle impacts into the side of the vehicle or other stiff object, you may be able to estimate the impact speed from the damage to the motorcycle. In tests done with motorcycles, the change in wheelbase can be used to approximate the speed, i.e. four inches of change in wheelbase equals approximately 20 mph (Baxter, 1993).

The investigator should keep in mind that this is an estimate, and any reference tests must come as close to replicating the collision as possible. In nighttime accidents, one may find that the motor vehicle operator misidentifies a motorcycle as another motor vehicle with one headlamp out and consequently misjudges the width of the vehicle especially when the motorcycle is turning. State and federal laws regulate the operation and equipment of motorcycles, and a thorough check of these regulations will assist in the investigation and reconstruction.

Bicycles are similar to motorcycles in that they are two-wheel articulated vehicles. Naturally, bicycles cannot reach the same speeds or possess the same force as a motorcycle, and the bicycle rider, unless struck by a car, usually has less severe injuries. Bicycles, like all mechanical devices, must be maintained and meet standards and regulations.

On a multiple-speed bicycle, there may be a front and rear derailleur. The derailleur is used to move the bicycle chain from one gear to the next. If the derailleur is not properly adjusted, it could come off the gear sprocket, stop the wheel and suddenly cause the rider to be propelled to the ground (Green, 1992). Bicycles, especially multiple-speed bicycles, are more complicated than most people realize. During an investigation, the investigator must consult all regulations and evaluate any maintenance problems. Bicycle accident investigation and reconstruction are similar to motorcycle and pedestrian accidents.

Pedestrian accidents usually carry the most severe injuries relative to the impact speed. The striking vehicle must be checked for any evidence such as blood, scrapes or clothing patterns such as jeans. By searching for this type of evidence, the investigator will be able to determine the dynamics and trajectory of the pedestrian. Depending on the geometry of the front of the vehicle, the pedestrian can either be forced to the ground or sliced in two. The pedestrian may also be thrown onto the hood and carried some distance before falling to the ground. There are several different trajectory patterns that pedestrians may take, and a review of subject references can distinguish between the types and suggest methods of determining the approximate speeds of the vehicle. One type of speed determination is made from the distance the pedestrian comes to rest after the initial impact. The distance could be from the pedestrian rolling or from being thrown through the air, but the methods must be determined. The formulas used to determine the speed of the vehicle from deceleration or skid marks can be used for any pedestrian rolling or sliding after impact to final rest. In tests performed with anthropomorphic dummies, the roadway coefficient of friction for a sliding or rolling pedestrian is approximately .7 to .10. These measures will vary depending on the surface, such as concrete or a sandy beach.

Additional evidence can be gathered by examining the medical records to determine injury patterns. For example, a leg injury equal to the height of the bumper of the vehicle would indicate the direction the pedestrian was walking since the leg closest to the bumper is struck first and usually exhibits a severe break. Also, determining the lateral distance from the initial impact to the point at which the

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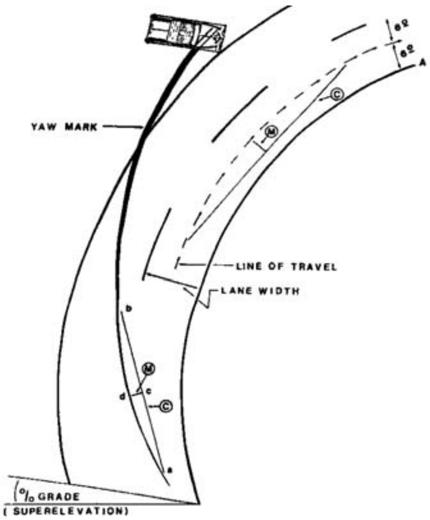
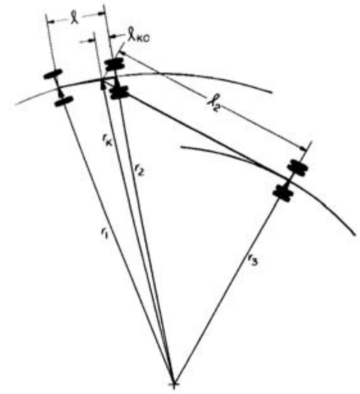
FIGURE 2





Max Offtracking
Rrear= √ R²front - L²wb
Rrear = rk-r3

Speed from YAW / Critical curve
S= 3.86 √ (R f +-m)
R=(Chord²/(8xM)+M/2)
M= Middle ordinate

Speed from a Vault

$$S = \frac{2.74xD}{\sqrt{Dx\cos Ax\sin A + -(Hx\cos^2 A)}}$$

Conservation of Momentum Impact with Stationary Vehicle

$$V1 = V3 + \frac{(W2 \times V4)}{W1}$$

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pedestrian strikes the hood or the windshield will also give an indication of the direction or path of the pedestrian.

Examining the pedestrian's shoes and soles may hold clues as to which foot the pedestrian had planted and a more exacting point of impact. Most pedestrian impacts have contact with the hood or with the windshield of the striking vehicle. Some investigators believe that the higher the pedestrian impacts the windshield, the better you can tell the speed of the vehicle at impact. This is very speculative at best since pedestrians come in all heights and weights, which affect the trajectory. Dents to the hood or fenders should be matched with the injuries of the pedestrian. This way, the dynamics of the impact can be evaluated.

With most pedestrian impacts, the subject of whether the pedestrian was walking or running is critical. There are several studies and efforts to attempt to clarify and quantify this elusive value. Some investigators strictly use studies or reference material without any consideration to replicating the subject pedestrian with the tested pedestrian. Some of the larger studies, especially with children, have simply marked off distances and have told the children to run "as fast as they can." Of course, not all pedestrians who are children run as fast as they can prior to impacts. A pedestrian may carry an object while running toward the street. This type of pedestrian cannot be equated with a pedestrian simply running "as fast as they can."

Ethics & Testimony

Ethics and testimony are very important in establishing the reputation of the investigator or reconstructionist. Ethics refers to professionalism and to knowing and doing what is professionally right or wrong. This does not mean that right or wrong refers to the criminal definitions but more to a moral definition.

One of the most important aspects is to eliminate any personal bias in your conclusions. Base the investigation and reconstruction on the evidence you see or hear. Interpretation of the physical evidence and witness testimony are the most important factors to rely on. Interpretation of evidence is a learned duty that must be dealt with professionally and accurately. If one is not trained for proper interpretation, an opinion will be false and misleading.

During an investigation, measurements and calculations will be used. The meas-

Vehicle Examination

Date Model Year Plate# Vin# Case# Name

Passengers# Passengers weight Curb weight Gross weight

Brake Pedal stuck? Steering Wheel Stuck? Speedometer Reading

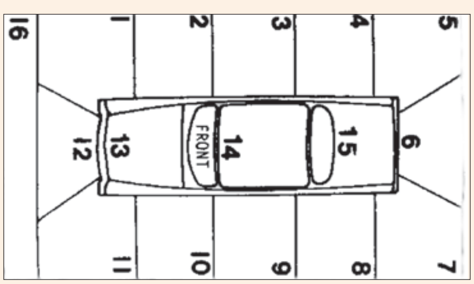
Wheels & Tires (Y/N)
Flat Hole Stuck Rim Bent Off Rim

RF
LF
RR
LR

Lamps& Bulbs (Broken Y/N)

Headlights Turnlamps Brakelamps
Front-left, right
Rear-left, right

Seat Belts used? (Y/N)



1 thru 15 topside damage - 16 undercarriage damage

S= severe M= moderate L= light

Remarks:

Damage Record

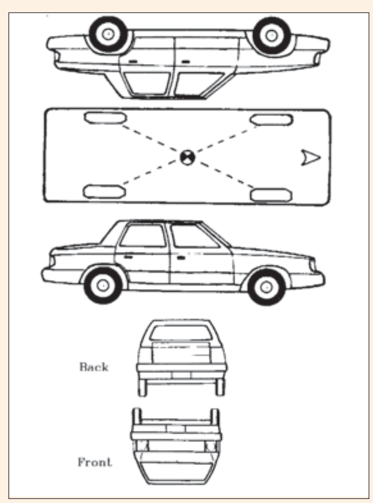
Date Model Year Plate# Vin# Case# Name

Curb weight Approximate load Total weight

Induced Damage=xxxxxxx Contact Damage=///////

Locked Wheel= {} Wheel Base =
Track Front= Rear=
Overhang Front+ Rear=
Vehicle Length Overall=

Length of Contact Damage=
Depth of Contact Damage= C1= C2= C3= C4= C5= C6= (at 6 point)



Remarks:

urements and calculations must be accurate and expressed appropriately such as in terms of approximately or at least, etc. Cheating or dishonesty in measurements and calculations will not only ruin your credibility but can easily be found out by the opposing expert.

When referring to opposing experts or witnesses, refrain from disparaging remarks and always treat the evidence or contrary opinions with honesty and decency. Avoid puffery and misleading statements in all your activities, including any opinion reports. Some investigations or reconstructions will undoubtedly include fatal injury cases. When working on these types of cases, especially autopsy photographs, consider your words carefully since the family or victims will likely become emotional reliving the event through your report and testimony.

Constantly working on cases takes a physical and mental toll on the investigator. It is healthy to take a break from stressful work so that your perspective will not be skewed and an incorrect interpretation will find its way in your analysis. Accident investigation and reconstruction is just as much of an art as a science since all the science in the world will not lead you to an appropriate opinion if you do not artfully examine and consider the evidence and science involved.

Accident investigation and reconstruction related to motor vehicles are not taught during a regular curriculum in engineering schools. Therefore, the art of interpretation and evidence gathering must be acquired from a different source. At best, college curriculum may teach you the science, but what you are really using is applied science. Professional investigators know when they must do research or ask for help if they are unsure of their findings.

An office library with books and articles relevant to the investigator's expertise should be used to the greatest extent. Additional and continuing education is also of primary importance since the art and science change rapidly. It is said and generally accepted that "an intelligent person never stops learning, and an ego believes it has learned everything." If after you have just begun your investigation it is apparent the results are not in your favor, you should advise the person you report to immediately so that neither of you will waste your time.

Testimony can be either at a deposition or at a trial. In either case, preparation for both must be done so that you are familiar with all aspects of the subject matter. During testimony at a deposition, you are required to answer questions posed to you and you are not required to expound on the answers. This is because the opposition attorney is usually the only one asking you questions in an effort to determine your credibility, accuracy and appearance. Usually, your client will refrain from asking questions unless s/he feels the need to correct or rehabilitate some of your answers.

During a trial, both your client under direct and the opposing attorney under cross-examination will question you. If you find the opposing attorney is mischaracterizing your testimony, you should expand on your answer so that the jury will have no doubt as to what you are saying. Testifying to a jury is much like telling a story to children or teaching a group of adults. Since most of your opinion is based in science and may be overly complicated, certain terms should be explained to jury.

Trial testimony can usually be supplemented with video presentations or computer animations. Some more complicated procedures and methods are usually best presented to a jury in these formats. The downside of video presentations and computer animations is that they may not always be admissible. The admissibility is with the judge, and it is usually based on simple and replicate video and computer animations. Over the years, I have used both and found that the simpler the presentation, the easier it is to be admitted at trial as well as understood by the jury.

Formulas & Mathematics

Formulas and mathematics are the basis of any investigation or reconstruction. There are approximately 200+ formulas used by the investigator and reconstructionist. Formulas are based on physics, mechanics and mathematics. Formulas are not created; they are developed and derived from known science.

The analysis of accidents must also use various sources such as weather, vision and lighting, pertinent regulations and specific research. One of the most used resources for motor vehicle accidents and occupant injuries involves analysis of crash testing data. Over the years, much data has been developed, but the investigator must locate the data and crash test that most closely replicate the subject investigation. The crash test may not exactly replicate the subject investigation; if not, the opinion or conclusions must state this so that the investigator would not be accused of misrepresentation or misuse of data. Most professionals perform some research and belong to professional organizations within their area of interest and can discuss situations or problems with peers.

There are too many formulas to list all of them here, but this discussion will examine various groups of formulas and list some at the end. Formulas using linear motion or constant velocity deal with time and distance. These formulas are used to determine constant velocity or time over a specific distance. For example, if you want to know the time it will take to travel 100 ft at a velocity of 10 ft per second, you would simply divide the 100 ft by 10 and arrive at 10 seconds. This is an oversimplification, but it gives the general idea.

Acceleration and deceleration can also be determined and are of value when attempting to calculate the speed of the vehicle at impact or the time and speed of an accelerating vehicle to reach a point of impact. One of the most used groups of formulas deals with conservation of linear momentum. The rule behind conservation of linear momentum states that momentum, which is weight times velocity, is conserved in any impact between two objects. It is crucial to know the weights of both objects, the point of impact, the distances from the point of impact to final rest and the coefficient of friction of the roadway.

One of the most common errors on the part of the investigator/reconstructionist is not using the correct formula once the evidence and dynamics of the collision are determined. Using the correct formula derived from a proper source is crucial for accurate results. Rear-end impacts may seem to be very straightforward or simple, especially when there appears to be no damage, but this analysis is one of the most complicated and, therefore, needs exacting analysis and calculations.

The yaw or critical speed formula is the speed at the beginning of the yaw marks or the maximum speed of the roadway curve. Knowing the maximum curve speed, i.e. 50 mph max curve speed, one can then state that the vehicle exceeded 50 mph, but the top speed is unknown. This is sufficient given that the speed limit of the curve is probably 35 mph or less.

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Maximum offtracking is the distance difference from the rear axel and the drive axels of a semi tractor-trailer. This calculation is important when the semi rolls over a curb and strikes a pedestrian standing on the curb. The speed from vault is to determine the speed a vehicle obtained prior to leaving the ground and vaulting through the air to the final rest position. This is important when a single vehicle leaves the roadway on its own due to excessive speed.

The momentum formula is used for a linear impact with a stopped vehicle. The calculations for angular impacts, i.e. intersections of 90º, are more complicated since both vehicles' speed after impact must be determined as well as the pre- and post-impact angles in relation to each vehicle. If a vehicle skidded prior to impact, the energy expended in skidding must be combined with the COM values.

Other fall, vault and flip formulas used are as follows:

7-1 is for a fall with a grade at takeoff;

7-2 is for a fall, flip and vault using an angle at takeoff;

7-3 is to determine the minimum takeoff angle for flips and vaults

7-4 is for minimum velocity at takeoff with an assumed 45º angle

$$7.1\ V = dx\sqrt{\frac{g}{2x(dxG - h)}}$$

$$7.2\ V = dx\sqrt{\frac{g}{2xcosAx(dx\ sinA - hcosA)}}$$

$$7.3\ A(°) = .5x\ cos^{-1}[\frac{h}{\sqrt{(d^2 + h^2)}}]$$

$$7.4\ V = dx\sqrt{\frac{g}{d - h}}$$

Investigation & Reconstruction Forms

Forms play an important part in any scientific procedure or method. Forms can be simple or complicated depending on the subject investigation. One of the more complicated issues needing documentation is damage measurement. To begin with, the principal direction of force of all vehicles must be determined. Then the collision damage classification is chosen.

The collision deformation classification is an alphanumerical system used by all investigators and reconstructionists to maintain consistency when documenting damage(Society of Automotive Engineers, 1980). The classification is a seven-character code. The first two represent the force direction related to a time clock, the third is a code representing the area of damage in relation to the sides, top and bottom of the vehicle, the fourth represents the damage in a longitudinal or lateral area, the fifth represents specific sections both vertical and lateral of the damage indicated in the fourth character, the sixth character represents the type of damage (wide, narrow, rollover), and the seventh and final character is the extent of permanent damage to a given area of the vehicle. This evaluation is used to input into several different computer programs to determine the severity of impact and extrapolate to the approximate speed prior to collision.

Forms can be most valuable when you consider the many items that can be forgotten and not recorded. One of the main purposes of forms such as those on pg. 10 (Andrews, 1995) is that you can prepare the forms in your office when you are not rushed, as with a vehicle or roadway inspection and, therefore, can list all the data that should be recorded during a vehicle or scene inspection. Hopefully, this way you will not forget crucial data. One of the most important forms is the data needed to perform a scale diagram after you leave the scene. The rough diagram is very important should someone need to return to the scene and locate the physical evidence. If the scene data and the scale diagram are not accurate, this physical evidence may be lost forever and will jeopardize your case. Most scale diagrams are constructed in either coordinate or triangulation procedures. These are the easiest and most accurate, given the time constraints and pressures at the scene. The coordinate method is normally used for city roadways, and triangulation is usually used for rural areas. Coordination uses two measurements, while triangulation uses three for each spot or location of the physical evidence.

The forms on pg. 10 are a simple example. You can develop and use your own forms. Forms are only as good as the design and use of the investigator or reconstructionist. ■

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