11 Accident reconstruction

(a) Introduction and objectives

Appropriate accident reconstruction is an essential task, assuming that causes should be identified so that preventive remedies can be determined. In other words, the ultimate objective is product or process improvement for future risk reduction. There may be some immediate subordinate objectives, such as fault determination for police action, for criminal or civil liability purposes, for insurance reports, for temporary site alterations or immediate equipment modifications, and for recall or regulatory actions.

Regardless of the purpose of an accident reconstruction, only time-proven, peer-acceptable, fact-based techniques should be utilized. A commonly accepted foundation for the analysis increases credibility and acceptability, while reducing conflicts in the findings and conclusions of others who might perform a similar reconstruction. The methods are generic, whether applied to passenger vehicle collisions, single earthmoving vehicle turnovers, an aircraft crash, some recreational vehicle impacts, a machine tool industrial accident, or any other accident situation. The content and words may be different, but the so-called ‘laws of physics’ remain the same. The time-honored methodology is immediately productive and it provides comparability in engineering terminology or replication in scientific research terms.

The accident reconstruction process generally begins with a site and vehicle investigation, proceeds to a literature search and the marshaling of supporting documentation or foundational information, and, finally, the preparation of reports and graphics. A follow-on effort is often advisable. While the process seems rather straightforward, there are always variations between investigators and analysts that could result in significant differences, complications, and even advocacy for vested interests. A bias might result from the use of more sophisticated available technology, the level of detail utilized, or philosophical differences. For example, in terms of philosophy, some safety specialists advocate faceless anonymity, faultless reports, or no-repercussion promises, since they believe that more honest reporting will occur if there is no possibility of suffering personal fault accusations or possible company liability. That process generally involves self-investigation and admissions. This chapter will emphasize the independent investigation, the broad scope required for an adequate accident reconstruction, and techniques to avoid common mistakes and omissions.
(b) The initial investigation

(1) Photographic documentation

As an accident scene is approached, photographs should be taken to record the scene before any further inadvertent damage could occur. Just the movement of people at the scene, including the investigators and rescue personnel, could move fragments of the vehicle on the roadway, obscure tire marks on a dirt shoulder, or bend sheet metal as they lean on the vehicle to look for something else. The photographs should be taken from all major directions to record the general scene. This includes all sides of the vehicles, the approach path of each vehicle or moving object, and photographs taken to document the beliefs and opinions expressed by witnesses. Whether an intersection collision, a construction equipment accident, or an industrial injury, an inquiry should be made of any changes or modifications made after the collision, accident, or injury. Such changes should be photographed to compare with any unchanged exemplars.

There are two important caveats: first, take at least two photographs of every view, preferably with two different cameras (a primary and a backup camera); and second, photograph everything, since something overlooked may become important later and human perception is such that key evidence may not be seen or properly interpreted until a review of the photographs occurs.

It may be important to use a camera monopod or tripod to maintain a constant camera height and location. Sight obstruction or blind-zone photographs should be taken at the eye height and the location of the person so encumbered. If police or company photographs are available and changes noted, similar photographs should be taken to record the before-and-after modifications.

For intersection collisions, all signage and other traffic control devices should be photographed. Orange cones may be used as locators or distance markers. The second round of photographs may include measurement rulers to demonstrate the accuracy and method of determining distances and dimensions. The location and direction of each photographic view should be marked on a rough sketch of the accident scene. Each photograph should be entered in a log with a notation of where, how, when, why, and by whom it was taken.

Cameras taking still photographs with film are preferable because they are difficult to alter. Digital cameras are more versatile, with high zoom potential, quick enlargement and printing, and large shot capacity, but are easily altered on some desktop computers. Videotape may be desirable to demonstrate key behavior, equipment movement, or changing views from a moving vehicle. They may assist in the preparation of computer-generated video graphics or large exhibits that can have accident overlays (transparencies) placed upon them.

Aerial photographs may provide important details, otherwise unseen, of a collision site. Various road gouges, tire marks, and debris trails may become visible. Cameras on balloons, fishing poles, and work platforms of boom cranes have been used for overhead shots of vehicles in a collision.

An automobile component replacement manufacturer experienced several serious injuries in its metalforming and joining area. Many of the punch presses, press brakes, and bending machines were poorly guarded. One old press had continual cycling until turned off by a wall switch and this was considered illegal by a retained independent safety consultant. Some safety recommendations were made, directly to the chief
executive officer, as to emergency guarding. But photographs of each machine were enlarged by office copiers to permit illustrative sketches of the locations on each machine where safeguards and warnings should be installed. Illustrative copies of temporary warnings and the sources of permanent warnings accompanied the photographs. The metalforming equipment of this aftermarket supplier was almost entirely previously owned (used), obtained at auctions. Such used equipment produced products with major dimensional variations, so the allowable discrepancy rate was high. These variations resulted in defects as originally manufactured and during wearout. The defects could produce an ignition source during vehicle collisions. The presence of an ignition hazard was unrecognized by the manufacturer or by the distributors and retail sales outlets that were supplied with the product.

(2) Measurements and diagrams

An on-site investigation provides the opportunity to observe, measure, and record a variety of relevant details concerning the presence of the roadway, its coefficient of friction, the road slope, visual obstructions, the sight distances, the traffic flow, the traffic control devices, possible skid marks, the accident vehicles, their positions at rest, the deformations on the vehicles, and many other factors or considerations. Each accident shares some commonality with others, but each is uniquely different. A preliminary estimation can be made of the approach pathways of vehicles involved in a collision, the impact location, and their post-impact trajectories. These are in the form of hypotheses against which all the evidence can be systematically compared and evaluated. The hypotheses may be modified to fit the facts and then serve as a model to be verified or rejected, in part or in whole, by a subsequent in-office analytic reconstruction of the accident.

There may be witness marks (scrapes and gouges) on the road surface that may suggest a post-impact movement of a vehicle. There may be tire skid marks that can be used to estimate the pre-impact speed of the vehicle. There may be a spiderweb type of windshield glass fracture, the center of which may have been caused by a human head impact. The slope or grade of the roadway and its coefficient of friction could be measured. Visual obstructions and their resultant blind zones could be recorded. All of this data may result in rough sketches or diagrams, with roadway and curb outlines, notes as to signs and signals, and, most importantly, reference points, landmarks, and baselines should be included. A table of measurements, between points on the street or in the vehicle, should be prepared. This assists in preparing accident situation maps and computer simulation graphics. This preliminary site evaluation may be redrawn for greater clarity and to scale at a later date, but the original sketches and notes should be retained in the accident file.

Some investigators distinguish between steering yaw or side sliding marks, acceleration scuffs or melted rubber tracks, and collision-induced scrubs or brushmarks. There may be an estimate of take-off, airborne, and landing speeds for vehicles running off cliffs, embankments, landings, or bridges. The investigator may utilize the injury patterns to determine injury causation. For example, a passenger in an automobile was forced downward by an upper torso belt routed over his shoulder from a near-floor mount. It appeared to be a cervical injury because the collision was at a relatively low speed and his shoulder was depressed by the belt. A tear-apart or degloving of the seat back revealed a major deformation of the steel back support. Major downward forces
had been applied to the passenger. A subsequent MRI image revealed a major disk herniation and extrusion in the pelvic (lumbar) area. **Caveat:** Occupant injuries should be considered as an integral component in the physical and human chain-of-causation that characterizes modern accident investigation and reconstruction.

Informal conversations with nearby residents may indicate that the collision site has a history of speeding vehicles, a high accident rate, a pedestrian injury problem at certain time periods in the day, a near-miss history of turning incidents, or changes in the duration or character of the traffic signals. Information about motor vehicle ownership may lead to past owner or operator interviews to determine vehicle repair, modification, recall, or damage incidents.

If there were a vehicle fire, the point of origin should be determined. It might be an engine compartment fire, a passenger compartment fire, or a fuel tank that was crushed in a rear-end collision. What was the burn pattern? Was there evidence of arson? Were combustible materials being carried? In one example, a severely burned driver had filled a gasoline can and carried it in the occupant compartment to assure that it would not tip over or leak. He did not know that the gasoline container was of a type disapproved of in some countries because it did leak and was not fireworthy. The burn pattern of another vehicle indicated an origin (lowest point of a v-shaped burn pattern, narrowest flame spread, and greatest heat damage) at the right rear wheel well. There was no evidence of drop-down burning such as gasoline on the ground. A badly deteriorated exhaust pipe was found that was located very close to the tire and the vehicle had been allowed to warm up in a stationary position, without the benefit of the air flow of a moving vehicle to reduce high temperature buildup.

In still another case, a gasoline tanker exploded while being filled with fuel. Static electricity was the likely ignition cause and gasoline vapors the fuel source. To assure proper grounding of the vehicle in the future, a grounding resistance detection system was installed at the gasoline terminal (to detect the electrical potential difference between the gasoline tanker vehicle and the ground of the terminal).

Measurement of vehicle crush is extremely important. Various devices are used to establish a perimeter base reference line. Then, measurements are taken between the reference perimeter and the crushed or distorted area of the vehicle. This is done in a series of crush zones, so there may be six crush zones with equally spaced measurements of depth of crush or vehicle bowing. The measurements should be taken perpendicular to the crushed surface, at the height of the deepest penetration. Based on the stiffness of the vehicle, the extent of vehicle crush may reveal the velocity (speed) of impact, the magnitude of forces applied, and the general crashworthiness of the vehicle. There are electronic sighting systems, used to take field measurements from a reference point to selected points on the vehicle (usually to a temporary marker or numbered patch). This data may be compared to the same points on the original vehicle, or it may be used to produce automatically a scale drawing at the accident site.

The skid marks left on the roadway may indicate that one vehicle was traveling 50 mph (80 km) in a 25 mph (40 km) posted area. The deformation on the front of V-1 (vehicle number one), and matching deformation on the driver’s side of the vehicle, may suggest that V-1 impacted the side of V-2. A passenger that is found on the roadway suggests occupant ejection of a non-restrained (unbelted) person. An opened alcoholic beverage container or package of marijuana in the vehicle interior suggests that further investigation is needed of possible driver intoxication and impairment. However, these are preliminary inferences that need to be verified by a more detailed analysis,
consideration of the totality of the accident, and further study of the relevant available literature and other information collected for the analyses.

There may be a need for a second or third visit to inspect a vehicle, either to recheck some neglected item that now seems important or to bring a specialist to examine some unique feature or condition. For example, samples of blood stains and flesh might be taken, teeth marks examined in greater detail, light bulb filaments that are whole or broken photographed more closely, and a more specific comparison made of the paint transfer from one vehicle to a vehicle that had been sideswiped. There may not have been locked wheel skid marks on the roadway, but the tire treads could reveal a particular pattern characteristic of the full engagement of antilock brakes, and all of the tire marks may need a further differentiation and explanation. The seatbelts may exhibit marks that show that an occupant may or may not have exerted considerable force against a locked seatbelt, but the manufacturer’s identification is necessary to determine whether they are original equipment, an aftermarket replacement, or have material degradation in belts supplied by one vendor. A missing element in a preliminary speed and control calculation might be revealed in a second inspection to be a smooth bleeding asphalt area in a vehicle’s initial approach pathway to a collision. Supplemental information on cell-phone usage, occupant bruises, and the possible movement of objects within the vehicle interior may warrant a reexamination of the vehicle and the accident site. The objects (such as a tire) may have been removed from the accident scene and not been known about at the time of the first inspection.

In some situations, only a quick bare-bones investigation is necessary. For example, two vehicles were stopped at a marked crosswalk to permit a young child to cross the road. An ambulance approached the rear of one vehicle, with flashing lights, and sounded its horn so that the automobile would clear its path. The vehicle moved out of the way, fearing an emergency, and was broadsided by another vehicle in the intersection. Was the ambulance (V-1) at fault, was it the vehicle (V-2) that moved out of the way, or was it the vehicle (V-3) that collided with V-2? The question was formulated by an insurance adjuster and referred to a law firm to determine fault. It was, in essence, a legal question requiring the application of local legal principles, rather than a technical question requiring sophisticated accident investigation and reconstruction. Only the police accident report and a few witness statements provided the limited factual information deemed necessary to resolve the legal issues. In other words, the character and extent of the accident investigation is needs-driven, so the specific purpose defines and limits the activity.

The basic purpose of the on-site investigation is to observe and identify all relevant information, measure and make diagrams of all important considerations, and to evaluate and document all factors that should be considered in a subsequent accident reconstruction.

(3) Traffic collision (police) reports

The police report of an accident is important because it documents what occurred shortly after the accident, before the evidence is taken away and the scene changes. Such a report is given great weight to the extent that it describes physical facts (evidence), documents measurements taken by the officer, and records the scene by means of photographs. Lesser weight is given to diagrams because they may be conclusionary guesses and based on the subjective opinions of those who claim to be eye-witnesses. The
names, addresses, vehicle identification, and accident location are generally considered reliable. The witness statements are usually taken at face value until controverted. They often indicate areas of conflicting opinions or possible disputes that need special attention. Since much of the report is ‘as told to him’ and is a search for immediate causation, such as ‘excessive speed for conditions’, in order to complete a checklist on the report, the final conclusions are generally less credible than the factual portion of the report. In general, the conclusions, opinions, and impressions are given far less weight and are generally inadmissible in court proceedings. The weight given often depends on the training and qualifications of the officer, the technical or legal complexity of the issues, and the character and extent of any subsequent supplemental report that can corroborate the findings. The police reports are generally helpful as to the presence of skid marks or tire marks, the time of day or night, the weather, lighting, roadway surface conditions (wet, ice, snow), sobriety, and the presence of traffic-control devices.

(c) The search-and-marshall effort

Immediately following the initial investigation, a search should be made for all sources of information that might be helpful in evaluating the facts and the hypotheses generated in the investigation. Subsequently, material deemed relevant should be marshaled in one file so that a solid foundation is available for analyses, the reconstruction conclusions, and the opinions that might be offered in adversarial situations.

The search may range from a quick review of the books, journal articles, and various reports immediately available to a detailed patent search (the patent file and wrapper). There may be valuable information in owner’s manuals, service manuals, vehicle specifications, and a variety of publications describing vehicle features and performance. There may be stopping distance data (from 60 mph to 0 mph) and vehicle crash stiffness coefficients (frontal, offset frontal, and side stiffness). There are portable braking test devices that measure acceleration and deceleration, speed and time, distance and grade, drag factors, and g forces (lateral, average, and peak).

There are firms that can provide complete reports on over 2000 NHTSA crash tests and those reports include crush measurements, photographs, dummy responses, and accelerometer graphs. For example, for one vehicle in a frontal collision with a fixed rigid barrier, at an impact speed of 35.1 mph (56.5 km/h), the average crush distance was found to be 17.7 inches (44.9 cm), and measurements at the center of six different zones ranged from 12.6 inches to 20.2 inches.

There are automotive publications describing the reasons for changes in company and government requirements. There are lists of recalls, federal preliminary evaluations and engineering analyses, and liability lawsuit allegations. There are private testing grounds and private sources of data. For example, one firm provides passenger vehicle and motorcycle specifications including weight, length, width, height, wheelbase, wheeltrack, front overhang, hood height, bumper height, turn circle, wheel radius, ground-to-hood, bumper-to-hood, bumper-to-windshield distances, etc. Another firm provides headlamp data, acceleration speeds and distances, braking distances, interior dimensions, materials used, and center-of-gravity information. Another provides information on crash tests of vehicles into guardrail terminals, into pedestrians, into bicyclists, and into signposts. Others provide a car-to-bus impact video, damage repair estimates, sun location, twilight times, weather condition, high accident intersections, and last bar visited. Almost anything needed is supplied by the accident reconstruction community.
It is important to view crash videotapes several times since important information may be revealed on a topic not suggested by the test title. For example, tests to determine possible leakage from gasoline tanks during rear-end collisions also show the violent head and upper torso movements of the test manikins and the type of airbag deployment.

(d) Analysis and reconstruction

(1) Vehicle crush

One reconstructionist, using a simple computerized crush model (EDCRASH, see p. 152), determined that a vehicle impact speed was 19 mph (30.6 km/h). This is a damage or crush volume model (six crush depths and a stiffness value), derivative of other CRASH (see p. 151) models, that provides a barrier equivalent speed. By using a simple rule of thumb, that each one inch (2.54 cm) of vehicle crush equals 1 mph (1.6 km/h), a 27-inch (68.6 cm) (maximum) crush distance would result in an impact speed of 27 mph (43.4 km/h), for localized, focused, or pole impacts. Using a police report that indicated a maximum crush of 24 inches (60.9 cm), the speed would be 24 mph (38.6 km/h), based on the rule of thumb method. Still another formula indicated an impact speed of 2.5 mph (40.2 km). The delta-V speeds were 23 mph (37.0 km/h) (EDCRASH), and 33 mph (53.1 km/h) (formula). The accident reconstructionist concluded that the impact speed was probably in the ‘mid-20s’ (38 to 42 km/h). The rebound or restitution was about 20% for an in-line frontal pole impact.

The general rule is the greater the crush and the greater the vehicle stiffness, the higher the impact speed. But the crush characteristics of each vehicle differ, depending on such factors as the configuration of various structural members in the crush zones. In the preceding evaluation, the impact speeds varied from 19 to 27 mph (30.6 to 43.4 km/h) and the delta-V speeds from 23 to 33 mph (37.0 to 53.1 km/h). These major differences are to be expected because of the different reconstruction models and the quality of the data being used.

Another accident reconstructionist, dealing with the same vehicle and accident, for a pole-impact maximum crush of 21 inches (53.3 cm), using a formula based on the impact data, estimated a speed of 20 mph (32.2 km/h). This was a delta-V of 20 mph (32.2 km/h), a barrier equivalent speed of 9 mph (14.5 km/h), and a peak g-loading of 16. By another method of calculation, still using crash-test data, the impact speed was 23 mph (37 km). Still another estimate was based on crash tests of similar vehicles, using a k-2 stiffness (11.3) factor, and resulted in a 19.6 mph (31.5 km/h) impact speed. His best overall estimate was a 20 mph impact (32.2 km/h). Allowing a curb impact reduction of speed of 5 mph (8.0 km/h), the original speed prior to curb and pole impact was about 25 mph (40.2 km/h).

His range of impact speeds was about 20 to 23 mph (32.2 to 37.0 km/h), as compared to the first reconstructionist’s 19 to 27 mph (30.6 to 43.7 km/h). His best estimate of 20 mph (32.2 km) (apparently biased toward the lower value) was compared to the mid-20s estimate (biased toward the upper values). Of significance was that all estimates were below the 30 mph (48.3 km/h) value used in early crash tests to determine regulatory compliance for various safety features.
(2) The crash-event sequence

A single-vehicle crash event sequence generally occurs over a time period of 100 to 140 milliseconds, but often in less than one-tenth of a second. This event sequence starts with an initial contact (impact) with another object and continues to disengagement, restitution, rebound, or additional vehicle movement in an altered direction. Each event sequence in multiple collisions is analyzed separately.

The accident reconstructionist may prepare a timeline diagram to show when each event occurs and the interactions that result between the occupants and the vehicle interior, components, and devices. The timeline includes the force-crash pulse or decelerative changes (g-loadings) that are experienced during the collision. The crush of soft metal produces low decelerative changes and the crush of more substantial materials produces higher deceleration or resistance to crushing and bending. The crash pulse may be relatively smooth if there are fairly uniform crush zones (controlled crush by design), but may reveal some high-magnitude pulses, spikes, or reactions at various points on the timeline. There are various company and published criteria as to such force–time pulses, including maximum vehicle deceleration criteria, average vehicle deceleration criteria, and occupant deceleration (biokinetics) criteria for head and upper torso that may or may not be exceeded. It is the crash pulse that is very important in reconstructing the most significant events that occur during a collision. For example, in a typical front-end collision, the upper torso restraints (shoulder belts) would have their slack removed (from looseness or comfort) as the occupant moves forward, since the occupant continues to move forward until restrained in some manner as the vehicle is decelerated. The belt spools out of its retractor until the belt webbing locks by an inertial or pendulum locking mechanism. A pretensioner may pull the belt back to move the occupant’s upper torso back into an upright position. The harmful levels apply, until the belt ruptures at a point of maximum stress (although some belts are not designed to fail, so there will be continued restraint during the entire crash sequence). The effect of the pretensioner is to move the occupant’s head backward enough to provide additional room for its subsequent forward motion. With a pretensioner, the forward horizontal head movement may be cut in half, thus changing where the head might impact, its force vector, and its relationship to a quick inflation and deflation of an airbag. There may be deployment of a knee bolster to alter the lower torso movement to prevent submarining under the instrument panel, and to help keep the occupant’s torso upright during the crash sequence. The energy-absorbing steering column may collapse if the tilting steering wheel and direction of impact of the upper torso are in alignment. Of course, there may be airbag deployments that cushion and return the head, before contact with hard objects such as the steering wheel and B-pillar. The collision may be from the side, but many protective devices were designed primarily for frontal impacts at about 30 mph full barrier. The collision may be from the rear, so the seatback may have a significant tilting or horizontal movement to the rear and the headrest (passive or active head restraint) may or may not be in an effective position relative to the occupants’ pre-impact position. There may be flying objects such as loose tires, tools, boxes, or canned goods (groceries). See Figure 11.1 for an illustrative crash sequence.

The crash-pulse information may suggest why certain damage appears in the vehicle and the force vectors being applied to occupants (biokinetics) that induce or produce specific injuries. There are specific issues usually derived from the crash event sequence...
diagram. For example, when did the seatbelt webbing fail or rupture and under what forces? Did the belts provide the expected benefit (occupant restraint) before they failed? Did they prematurely fail or tear apart because of a deteriorated or original understrength condition? An essential caveat is that each collision and vehicle may result in a different detailed time–event sequence, depending on where and how the vehicle was impacted and whether the occupant was upright, slouched, turned, or out of position (OOP).

The collision event sequence might be compared with what occurred in early design from sled testing or from full vehicle crash testing of exemplar or similar vehicles. There may be significant differences in preproduction tests using an average-size dummy or subsequent testing by various public or private entities. It may be necessary to determine the effects of vehicle repairs, modifications, accessories, environmental factors, and unique vehicle movements such as rotation, rollover, and secondary impacts. Gradually, a clear understanding of what happened and what caused the injury or damage will be revealed.

(3) **Black-box data**

Many vehicles have collision recording devices, a crash data retrieval system, and a data link connector. Data from such a system is often referred to as black-box data. It is similar in concept to aircraft flight recorder systems. It can provide pre-collision and crash information in an encoded form that can be translated for use (Rosenbluth, 2000).

The crash data retrieval system (CDR) may store data in the airbag sensing and diagnostic modules (SDM). Such data may include vehicle speed, engine speed, percent throttle, and brake switch circuit status in 1 second intervals for 5 seconds before the crash. Some modules include seatbelt usage, malfunction dashboard indicators (lights), and passenger airbag disablement.
Other black-box systems use the electronically saved data for diagnosis and repair. The data may pertain to airbags (SRS), antilock braking systems (ABS), automatic traction control (ATC), cruise control (CC), engine fuel management (EFI), and seatbelt tensioners (ETR). The information is available in a read-only memory, in diagnostic trouble codes (DTCs), and is downloaded from the vehicle electronic control unit (ECU) by use of a repair level or engineering level scanner or microprocessor interface for one or more system units. For example, vehicle velocity conversions into miles/hr or km/hr could reveal speed changes before and during the crash sequence.

The accuracy of the data may be open to question. For example, the longitudinal accelerometer used to generate post-crash delta-V graphs may have to be corrected for side-impact vectors if known. Thus, the availability of such data does not mean the collision scene patterns of debris, tire or skid marks, crush deformation, witness statements, and other information are not necessary or only corroborative. Each information source has its own value and standing in terms of credibility for a particular situation.

(4) Momentum and energy

In a collision, momentum \((mv)\) remains the same pre-impact and post-impact. Thus, momentum equations can be used without considering the damage to colliding vehicles or considering energy relationships. The kinetic energy (KE) or energy of motion does change as a result of a collision, because much of the energy may be consumed in creating the damage (crush). These facts are used for the energy or damage method, as contrasted with the momentum method of analysis.

There is a variety of techniques to determine pre-impact speeds, impact speeds, changes that occur during collisions, the exit speeds and directions after vehicle disengagement, and the final resting points. The time-based history of collision events may result in an illustrative graphic printout depending on the software used in a computer-generated analysis. In general, these calculations are based on momentum and kinetic energy equations (see pp. 153–4). The factual information necessary for calculations could include the mass of the vehicle, its wheelbase, degree of braking, the damage location and contour, the direction of deformation, rotational inertia, and intervehicle sliding. It may include a spin analysis and vaulting analysis. Different specialists may have differing opinions on whether energy calculations are better than momentum calculations, so both are generally advisable.

The computer models must often utilized by accident reconstructionists include the following.

- **CRASH** (Cornell Reconstruction of Automobile Speeds on the Highway). There is also CRASHEX (CRASH Extended), WinCRASH, and m-crash.
- **SMAC** (Simulation Model of Automobile Collision). There is also M-SMAC, the McHenry Version of SMAC, and WinSMAC from AR Software, Redmond, WA.
- **IMPACT** (Improved Mathematical Prediction of Automobile Collision and Trajectory).
- **TBS** (Simplified, Interactive Simulation for Predicting the Braking and Steering Response of Commercial Vehicles).
There are other models such as HVOSM and AITools-Linear Momentum. Based on the SMAC model, there are trademarked programs such as EDCRASH, EDCAD, and EDVAP, by Engineering Dynamics Corporation, Beaverton, OR. Other companies and consultants have modified models or personal models.

There are rollover animated models that show vehicle motion, occupant motion, restraint system function, and impacts. There are acceleration recorders to measure acceleration events and force–time acceleration wave forms, during either vehicle handling or crash testing. In fact, there are many other tools of the trade that can be used by accident reconstructionists to solve almost any issue.

(5) Injury classifications

Understanding the injury may become a vital part of an accident reconstruction, since specific injuries may lead to inferences about injury causation and product deficiencies. For example, a leg fracture may suggest that the leg was flailing about during the collision, the lower torso submarining under the instrument panel, or the inward crushing of the vehicle that compromised the leg space in the interior of the vehicle. Similarly, a lower spine (lumbar) injury may suggest a violent pitch-down of the vehicle during rebound and a possible problem with a metal or plastic pelvic restraint in the forward position of the seat cushion area.

In general, the location and magnitude of the specific injuries are the prime focus, not some general understanding or method of injury classification. However, commonly accepted or consensus methods of evaluating general injuries do have some value for company activities related to injury pattern and trend identification (the cumulative magnitude of injuries), pareto (worst injuries first) studies, and for cost–benefit evaluations comparing actual injury costs and possible design improvement cost–benefits.

General injuries may be rated or assessed as to their severity by various techniques as suggested by the following acronyms that may be found in accident records.

- **GCS** (Glasgow Coma Scale, used for head injuries based on eye opening, verbal response, and motor response).
- **CRAMS** (Circulation, Respiration, Abdomen, Motor, and Speech).
- **IPR** (Injury Priority Rating, an impairment assessment based on mobility, cognitive, cosmetic, and pain categories, also levels).
- **AIS** (Abbreviated Injury Scale, used to classify injuries into one of seven categories). If there is more than one injury, an Overall AIS (OAIS) classification procedure may be used. A zero indicates no injury and a 7 indicates it is virtually unsurvivable.
- **ISS** (Injury Severity Scale, assesses the synergistic effects of multiple body injuries).
- **HIC** (Head Injury Criterion, discussed in detail elsewhere in this book).
- **HARM** (a method of combining injury levels and assigning economic values to the injuries).
- **MISS** (Modified Injury Severity Score).
- **RTS** (Revised Trauma Score). A trauma score used for rapid assessment and treatment prioritization.
- **TRISS** (Trauma Score plus ISS, used to assess injury to lower-age individuals).

There are other methods in use, but they do not utilize the results of detailed neuropsychological testing, the findings of neurosurgery, or the subsequent neurological treatment, recovery, or residual condition.
Basic terminology

It is important to have a basic understanding of the relevant terminology when reviewing investigation, reconstruction, or police reports about an accident. Some key definitions (in commonly used non-technical language) are as follows.

Delta V
When two vehicles collide, there may be a change in the direction of travel (pathway) of each vehicle and a change in speed. Together, the speed and direction is called velocity. In a collision, the change in velocity of a vehicle is called delta-V (ΔV). There is a relationship between each vehicle’s delta-V, its initial and post-impact momentum, and the energy lost or transferred in the collision.

Impulse
Each vehicle may be subject to a force from another colliding vehicle. That force may be exerted for a certain time duration. The magnitude and duration of the force, specifically the area under the force–time curve, is known as an impulse.

Contact time
The duration of force applied in a collision is generally 0.1 to 0.2 seconds and is known as the contact time. The maximum force is generally about two or three times the average force exerted during the contact time.

Momentum (p)
This is the product of the mass (m) times the velocity (v) of the center of mass of the vehicle. The change in momentum, of the center of gravity, is equal to the impulse (m) applied to it.

\[ p = mv \]

Mass (m)
This is the weight divided by the acceleration of gravity or \( m \cdot \frac{w}{g} \). That is, weight divided by 32.2.

Rebound
The surface of a vehicle will rebound or elastically move back in the opposite direction of the forces first applied. The rebound is about the same as the relative velocity in the initial impact (less considerable energy lost in metal crushing and sliding friction). Note: differentiate rebound from restitution and the rebound in suspension systems.

Force (F)
A vector (magnitude and direction) capable of accelerating a mass:

\[ F = ma \]
Acceleration ($a$)
The time rate of change in velocity. A *jerk* is the time rate of change in acceleration. Expressed as feet per second per second.

Kinetic energy ($KE$)
The ability to do work due to the motion of a mass:

$$KE = \frac{1}{2} mv^2$$

(7) General terminology
Of some value are the definitions of words and abbreviations commonly used in accident reconstruction documents, expressed in a simple non-technical manner. The following are some of the most common.

Antilock brake systems (ABS)
The use of a microprocessor, electronic sensors, and hydraulic components to automatically pump (apply) the brakes very rapidly and repeatedly to avoid wheel lockup, tire skids, and to achieve maximum braking efficiency.

A-pillar
The roof supports at the windshield. Other roof supports are the B-pillar (between the front-door window and the rear door window of a sedan), the C-pillar at the rear of the windows, and the rearmost is the D-pillar on some vehicles.

Ball joint
The flexible ball-and-socket joint used in front suspensions.

Beltline
The line formed around the vehicle’s body defined by the lower edge of the vehicle’s glass window panels.

Bobtail tractor
A truck tractor without an attached semitrailer.

Brake modulation
The varying brake-pedal pressure needed to hold the brakes in full engagement, but less than that needed for brake lockup, which could result in reverted rubber skidmarks (lesser braking efficiency).
Camber
The tilt in the wheels inward (negative camber or top tilt-in) or outward (positive camber or top tilt-out).

Caster
The amount (angle) that the wheel pivot axis is located ahead of where the tire meets the ground, so that the wheel trails behind the pivot and tends to self-center. More specifically, it is the longitudinal inclination of the steer rotation or kingpin axis. A positive caster exists when the steer axis (ground intercept) is ahead of the tire contact (the center of the tire ground footprint).

Center of gravity
The point in a vehicle about which it is in perfect balance regardless of how it may be turned or rotated.

Chassis
The parts of a vehicle attached to a structural frame (rails) or, for vehicles with unitized construction, everything but the body of the vehicle.

Class 8
The highest category of heavy trucks based on gross vehicle weight. Class 7 is medium-duty.

COE
Cab-over-engine truck.

Compliance
The resiliency of suspension bushings that cushion road bump shock, with some rearward motion but no lateral movement during cornering. Affects harshness of the ride and vehicle handling.

Contact patch
The circular or elliptical area in which the tire tread is in contact with the roadway or ground.

Cruise control
A device in which an electronic controller monitors the vehicle speed as compared to driver’s set speed and activates the throttle linkage to maintain the desired speed.
Derivatives

Vehicle models using the same platform.

Drive-by-wire

The elimination of mechanical components between the driver and the vehicle. The use of electrical and electronic signals reduces mechanical linkage routing problems, wearout potential, and vehicle servicing requirements.

Eye ellipse (eyellipse)

A side-view representation of the scatter of eye points of vehicle drivers.

Fatigue fracture

The progressive growth of cracks in metal, from bending cycles and intermittent varying stresses, until the metal fractures completely. Usually manifested by progression, beach, or clamshell marks.

FCIS

Front cab isolation system, a vibration-reducing suspension system for trucks.

Fifth wheel

A coupling device attached to a truck tractor chassis that can pull a semitrailer and support about half the semitrailer weight.

Floorpan

The metal stampings that form the floor and serve as the foundation for the vehicle’s mechanical parts. It serves to fix the dimensions for many structural and external panels.

FMCSR

Federal Motor Carrier Safety Regulations (USA).

FMVSS

Federal Motor Vehicle Safety Standards, published by the National Highway Traffic Safety Administration (USA). May be subject to revisions and serves as a minimum standard for the areas specifically included.

Gasoline (petrol)

The petroleum hydrocarbon fuel used to power internal combustion engines. May contain extra butanes and pentanes in the winter, inhibitors of oxidation and gum formation, antiknock agents, surficants, and dyes.
Gravity acceleration

32.2 ft/sec$^2$.

HIC
Head injury criterion.

H-point
The point of rotation of the hip joint of an occupant seated in a vehicle. See SAE Standard J826 for specification details.

HVAC
Heating, ventilation, and air conditioning system (climate control).

IC
Integrated circuit (electronics).

ISE
Initial impact speed estimation.

LED
Light-emitting diode.

LP
Liquid propane gas (fuel).

Macro
Visible to the human eye.

Metallography
The process of polishing the face of a fractured metal surface, etching it, and examining the microstructure under optical magnification of about $1000\times$.

Micro
Visible by optical microscopes.

MMI
Multimedia interface (telematics).
OEM
Original equipment manufacturer.

Oversteer
A vehicle handling condition in which the rear of the vehicle swings wide or loose.

Pitch
Usually, the upward or downward movement of the rear of a vehicle about its longitudinal axis. The angular velocity is about the side (left to right) axis of the vehicle.

PLP or PRP
Principal locating point or principal reference points. Used to measure the deviation (location) of vehicle members from a standard reference point to determine assembly dimensional errors or the extent of collision deformation.

Prime mover
The tractor that tows or pulls trailers, construction equipment, or farm implements. That is, the self-powered vehicle or power unit for propulsion.

RDS-TMC
Radio data service – traffic message channel (Europe).

Ride-down
When a vehicle occupant is restrained and moves in conjunction with the vehicle, the occupant rides down the crash deceleration rather than being in free flight. The occupant experiences no spikes or jerks separate from the vehicle under ideal conditions.

Ride steer (bump steer)
A condition in which a wheel steers slightly with changes in suspension extension and compression.

Roadholding (lateral acceleration, cornering limit)
The vehicle’s grip on the road. Measured in g levels achieved at the maximum speed at which a vehicle can negotiate a given curve.

Roll (sway or lean)
The rotation of a vehicle body about its longitudinal axis. Occurs when the vehicle’s center of gravity is higher than the rotation axis. It may be sideways turnover of the vehicle. The angular velocity is around the longitudinal axis of the vehicle.
Roll steer
Steer angle changes due to suspension roll.

ROPS
Rollover protective structures that are used to protect occupants. May be a safety cage for construction vehicles such as bulldozers. Used for protection during side-over-side or end-over-end tipovers and rollovers.

SEM
Scanning electron microscopy.

Slack adjuster
The lever that serves to increase the pushrod force on the brakes of a truck.

Slap
Noise from tires traversing expansion joints, tar strips, and road seams.

Speed (v)
The distance traveled per second or hour, e.g. 60 mph (88 feet per second or 96.54 km/h).

Sprung weight
The vehicle weight supported by its suspension system.

Square wave crush
A vehicle deceleration (time–force) curve of fairly constant magnitude.

Steer angle
The difference between where the vehicle is headed (velocity) and the wheel plane (wheel direction).

Stress
Force per unit area.

Target vehicle
The vehicle that is impacted or targeted.
TEM
Transmission electron microscopy.

Thump
Audible periodic sound generated by a tire.

Toe-in and toe-out
If the forward portion of the wheel is turned inward it is a toe-in; if outward it is a toe-out.

Torque
The product of a perpendicular force acting over a given distance.

TPO
Thermoplastic olefin composite plastic (interior trim). Used for high-impact performance for head impact, air bag deployment, and B-pillar covers.

Traction
Traction is a measure of the force derived between a tire or tractive device and the roadway or other medium in which the tires operate. The difference between gross tractive force (theoretical) and net tractive force (actual pull) is the towed force.

Trajectory
Path of motion.

Transfer case (second transmission)
The transmission component that permits a vehicle to go to or from two- to four-wheel drive.

TSP
Telematics service provider.

ULF
Ultra low frequency radio waves.

Understeer
A vehicle-handling condition in which the vehicle resists turning and wants to continue in a straight line. It is a slip angle problem of the front tires as compared with the rear tires.
VHF
Very high frequency radio waves.

Wheel hop (axle tramp)
Lifting of a tire from full contact with the road, usually the right rear wheel under power.

Wheel stops
Concrete or metal chocks used as stops for vehicles in parking areas. May damage vehicle undercarriages, permit excessive bumper overhang, result in one-wheel tire contact, and serve to trip pedestrians. Contrast with continuous curbing and guardrails.

Yaw
Usually, the sideways movement of the front of a vehicle. It is the angular velocity about the vertical axis of the vehicle.

Yield stress
The stress level at which plastic deformation is initiated.

(e) Reports and graphics
An important decision is how to report the accident reconstruction and its derivative findings. It may sound simpler and easier to make an oral report or have an off-the-record discussion with a responsible design group. Sometimes only a brief conclusion conveyed to a supervisor is necessary. The objective should be to preserve a product’s history because design engineers who learn about the problem may soon retire, leave work, or be transferred to another job. All too frequently, new engineers repeat the same old problems. A written report, oriented toward product improvement and intended for future model production, could serve a valuable experience-retention function. The very process of preparing a written report generally requires greater attention to detail, accuracy, and conformity to recommended practices. It should be prepared with the company record-keeping policy and who the potential readers of the document might be in mind. For example, how would it look or be interpreted if the report eventually emerged before a court, a legislative committee, a regulatory agency, or a competitor seeking market advantage? In this regard, there should be completeness, adequate factual foundation, an avoidance of speculation, and cautious use of words. Parsimony may be preferable.

Is there a way in which there could be a very quick transfer of information, assuming the reconstruction has identified a specific defect and suggested a silent recall or some other means to correct the problem? Could the communication be done without possible adverse publicity that could cause harm to a brand image?

The accident reconstructionist may have the computer software to generate and print accident scene diagrams that are simple or complex, black-and-white or color, and static or animated. There are many companies that specialize in realistic 3-D animations that
are quite effective, but sometimes expensive. There may be photographic enlargements, medical illustrations, timelines, charts, graphs, document cleaning and highlighting, and the use of human digital modeling. The ultimate question is how best to communicate to a target audience the significant facts and conclusions in a fast and convincing manner that promotes action where warranted. This also means avoidance of an uninteresting and complex reading burden on others that might result in avoidance, dismissal, or forgetfulness of the results.

(f) The follow-on

It is important that the manufacturer be informed of safety problems discovered from accident investigation and reconstruction. It is not enough to inform the company’s insurance, legal, reliability, quality, warranty, marketing, or their testifying experts’ department. The reason is simple: the responsible engineers must know if the safety problem is to be corrected on existing products and prevented on the new products being designed or that will be designed. The responsible engineers may coordinate with those identified in the company’s policy manual or organizational responsibility charts as being ultimately responsible for overall product safety. This coordination is to secure a range of options as to what to do and how to do it, to assure that there is management approval, and to act in accordance with financial and public relations constraints.

A periodic follow-on effort is needed for a company to benefit from the in-field accident reconstruction activities performed by any person or group. This is because of the following five factors.

(1) Isolation

It is not unusual for the design engineers to be isolated within the company, and to be focused almost completely on new product design. The old products may be relegated to the less experienced. They may believe that their personal responsibility ends with the approval of their final design. For example, several military helicopters crashed, and accident investigators traced the problem to where some electrical lines that passed through a hole in the bulkhead became frayed and short-circuited. The problem received considerable publicity. About a year later, during a visit to the company, the problem was mentioned to the two design engineers responsible and their supervisor. The expressions on their faces and verbal remarks indicated complete surprise. Nobody had told them!

(2) Forget and repeat

It is not unusual in the automotive industry to discover a safety problem, resolve it for the next few models, then have it reappear five or 10 years later. This may result from the transfer, replacement, advancement, or retirement of those who hold the relevant knowledge. New engineers may not benefit from the historical experiences stored in the memory of former employees. In essence, there may not be a formal system of experience retention.

(3) Not proven

It is very easy to assume a personal and company defensive posture, to tell others ‘prove it to me’, and thus not assume the additional work involved in accepting a negative
finding of a possible safety defect. The proof required may vary from ‘just a little more’ to a burden that approaches the ‘impossible’. A high burden may be perceived as protecting the company, manifesting an appearance of loyalty to the company and its engineers, and saving time and effort on a past generation of products no longer earning money for the company. It is an avoidance of personal blame for recognizing something negative, rather than perceiving the positive aspect or the need for action.

(4) Reputation

A public perception may grow that there must be a safety defect, deficiency, or problem with a product. But the technical or company perception may be that there is no such problem. The issue is not whether there is a real problem, because public opinion and customer belief is, in fact, the problem. Unfortunately, public opinion generally trumps technical opinions. In such situations, something substantial must be done to protect the reputation of the product, brand, or company. For example, a distributor or seller may provide poor service, overcharge, misrepresent, be less than honest with the customer, and have negative interpersonal relationships. In one such situation, the manager indicated that this was just typical marketing promotion, with a focus on sales, and that some exaggeration or puffing always occurs. He remained silent about poor service operations and deviations from prescribed repair procedures, as if there was nothing wrong with what was occurring. Factory representatives felt otherwise. For them, product reputation and market share was at stake.

Some companies have spent a great deal of money attempting to deny a safety problem, because it was embarrassing to their design engineers and in conflict with some representations made to the customer base and government agencies. If denial is done, an equally important effort should be made to remedy the causes of the adverse public relations by what appear to be positive and constructive actions. Adverse opinions often grow into long-term difficulties, so follow-on activities need to be equally long-term in character.

Engineers involved in accident investigation and reconstruction sometimes have a basic ethical conflict between client confidentiality and their moral, sometimes legal, obligation to disclose dangers to the general public. The engineer may discover a safety problem, but what should he do? One rational approach to disclosure is to engage in reasonable dialog and follow-on efforts to encourage remedies to substantive safety problems. The proponent of change should be aware that you can’t fight city hall unless you are very diplomatic, convincing, persistent, and willing to listen to the other side.

(5) Previously overruled

Many companies perform costly advanced engineering studies lasting months or years for proof of concept, technical feasibility, pricing, compatibility, and possible benefit to future products. A particular study may meet all criteria, be approved, internally coordinated, and actually published as a company design study. Then someone in the chain of command or coordination procedure may state that it is not presently needed for marketing, that it is disapproved pending further study, or that it should be ‘stock-piled’. Once overruled or placed on the shelf, such studies are rarely resurrected, since others may believe that there could be some unknown reason for the non-acceptance. An accident investigation and reconstruction with a recommended remedy may identify
a need, but an earlier overruled design study may have been filed, long forgotten, and provide a remedy already evaluated. Where appropriate, the company accident reconstructionist or recipient of his report might review prior design studies to determine their applicability and possible use. It may save time and money by avoiding an essentially duplicate study. Thus, the follow-on effort may include activities extending beyond a simple reminder that something needs to be done.